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Licenciatura em Engenharia de Produção Industrial, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa

Decisions of technology innovation: The role of indicators

Dissertação para obtenção do Grau de Doutor em

Avaliação de Tecnologia

Orientador:	António Paulo Brandão Moniz de Jesus, Professor Associado com Agregação, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa
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FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

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In memoriam of my grandmother Lucília

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Abstract

This work presents research conducted to understand the role of indicators in decisions of technology innovation. A gap was detected in the literature of innovation and technology assessment about the use and influence of indicators in this type of decision. It was important to address this gap because indicators are often frequent elements of innovation and technology assessment studies. The research was designed to determine the extent of the use and influence of indicators in decisions of technology innovation, to characterize the role of indicators in these decisions, and to understand how indicators are used in these decisions. The latter involved the test of four possible explanatory factors: the type and phase of decision, and the context and process of construction of evidence. Furthermore, it focused on three Portuguese innovation groups: public researchers, business R&D&I leaders and policymakers. The research used a combination of methods to collect quantitative and qualitative information, such as surveys, case studies and social network analysis.

This research concluded that the use of indicators is different from their influence in decisions of technology innovation. In fact, there is a high use of indicators in these decisions, but lower and differentiated differences in their influence in each innovation group. This suggests that political-behavioural methods are also involved in the decisions to different degrees. The main social influences in the decisions came mostly from hierarchies, knowledge-based contacts and users. Furthermore, the research established that indicators played mostly symbolic roles in decisions of policymakers and business R&D&I leaders, although their role with researchers was more differentiated. Indicators were also described as helpful instruments to conduct a reasonable interpretation of data and to balance options in innovation and technology assessments studies, in particular when contextualised, described in detail and with discussion upon the options made.

Results suggest that there are four main explanatory factors for the role of indicators in these decisions: First, the type of decision appears to be a factor to consider when explaining the role of indicators. In fact, each type of decision had different influences on the way indicators are used, and each type of decision used different types of indicators. Results for policy-making were particularly different from decisions of acquisition and development of products/technology. Second, the phase of the decision can help to understand the role indicators play in these decisions. Results distinguished between two phases detected in all decisions – before and after the decision – as well as two other phases that can be used to complement the decision process and where indicators can be involved. Third, the context of decision is an important factor to consider when explaining the way indicators are taken into consideration in policy decisions. In fact, the role of indicators can be influenced by the particular context of the decision maker, in which all types of evidence can be selected or downplayed. More importantly, the use of persuasive analytical evidence appears to be related with the dispute existent in the policy context. Fourth and last, the process of construction of evidence is a factor to consider when explaining the way indicators are involved in these decisions. In fact, indicators and

other evidence were brought to the decision processes according to their availability and capacity to support the different arguments and interests of the actors and stakeholders. In one case, an indicator lost much persuasion strength with the controversies that it went through during the decision process. Therefore, it can be argued that the use of indicators is high but not very influential; their role is mostly symbolic to policymakers and business decisions, but varies among researchers. The role of indicators in these decisions depends on the type and phase of the decision and the context and process of construction of evidence. The latter two are related to the particular context of each decision maker, the existence of elements of dispute and controversies that influence the way indicators are introduced in the decision-making process.

Keywords: Technology innovation; indicators; evidence; decision-making; policy-making; technology assessment.

Sumário

Este trabalho apresenta uma investigação realizada para compreender o papel dos indicadores nas decisões de inovação tecnológica. A necessidade deste trabalho baseou-se na escassez de informação em relação ao grau de utilização e de influência dos indicadores nas decisões de inovação e de avaliação de tecnologia. Esta lacuna é particularmente relevante por os indicadores serem elementos frequentes nos estudos de inovação e de avaliação de tecnologia. A investigação foi orientada no sentido de determinar a extensão do uso e da influência de indicadores nas decisões de inovação tecnológica, caracterizar o papel dos indicadores nestas decisões e compreender como são utilizados os indicadores nestas decisões. Responder a esta última questão envolveu o teste de quatro possíveis factores explicativos: o tipo de decisão, a fase em que esta foi tomada, o contexto da decisão e o processo de construção de evidências. Para além disso, a investigação concentrou-se nos três grupos de inovação portugueses: o dos investigadores públicos, o dos líderes das empresas envolvidas em investigação, desenvolvimento e inovação e o dos decisores políticos. A pesquisa combinou métodos quantitativos e qualitativos, tais como inquéritos, estudos de caso e análise de redes sociais.

Os resultados apontam para uma utilização de indicadores diferenciada da influência real que estes têm nas decisões de inovação tecnológica. De facto, os resultados indicam a existência de uma utilização intensiva de indicadores nessas decisões, apesar de existirem diferenças significativas em relação à sua influência real em cada grupo de inovação. Estes dados sugerem o recurso a métodos políticos-comportamentais em diferentes graus. As principais influências sociais detectadas nas decisões tiveram sobretudo origem nas hierarquias, nos contactos baseados no conhecimento e nos utilizadores. Para além disso, a investigação aponta para que os indicadores desempenhem papéis maioritariamente simbólicos nas decisões dos responsáveis políticos e dos líderes das empresas envolvidas em I&DI, embora o seu papel junto dos investigadores públicos tenha sido mais diferenciado. Os indicadores foram também descritos como instrumentos úteis para realizar uma interpretação razoável dos dados e para equilibrar opções em estudos de inovação e de avaliação de tecnologia, em particular quando os indicadores foram contextualizados, descritos em detalhe e acompanhados de uma reflexão sobre as opções tomadas.

Os dados sugerem a existência de quatro factores principais para explicar o papel de indicadores nessas decisões. Em primeiro lugar, o tipo de decisão pode ser um factor a considerar ao explicar o papel dos indicadores, pois os resultados sugerem que para cada tipo de decisão correspondem diferentes formas de utilização de indicadores e diferentes tipos de indicadores. Os resultados revelaram diferenças mais significativas para a tomada de decisão política. Em segundo lugar, a fase da decisão pode ajudar a compreender o papel dos indicadores nestas decisões. Foram detectadas duas fases em todos os tipos de decisão (antes e depois da decisão), bem como duas outras fases que podem ser usadas para complementar o processo de tomada de decisão e em que os indicadores podem estar envolvidos. Em terceiro lugar, o contexto de decisão é um factor importante

para explicar a forma como os indicadores são levados em consideração nos processos de decisão política. Na verdade, o papel dos indicadores pode ser influenciado pelo contexto particular do tomador de decisão, no qual quaisquer evidências podem ser selecionadas ou minimizadas. De forma ainda mais relevante, a utilização de evidências analíticas persuasivas parece estar relacionada com contextos de maior disputa política. Em quarto e último lugar, o processo de construção de evidências é um factor a considerar ao explicar a forma como os indicadores são envolvidos nestas decisões. De facto, indicadores e outras evidências foram envolvidos nos processos de decisão estudados de acordo com a sua disponibilidade e capacidade para apoiar os diferentes argumentos e interesses dos atores e partes interessadas. Num dos casos, um indicador perdeu significativamente a sua capacidade de persuasão com as controvérsias que enfrentou durante o processo de decisão.

O estudo permite concluir que os indicadores são utilizados de forma significativa, embora não sejam muito influentes nas decisões de inovação tecnológica analisadas. O papel dos indicadores é principalmente simbólico nas decisões políticas e empresariais, e mais variado nas decisões dos investigadores. Os resultados apontam também para que as decisões dependam do tipo e da fase da decisão, bem como do contexto e do processo de construção de evidências. Estes dois últimos factores parecem estar relacionados com o contexto particular de cada decisor, e com a existência de disputa política e de controvérsias que influenciam a forma como os indicadores são introduzidos no processo de tomada de decisão.

Palavras-chave: Inovação tecnológica; indicadores; evidências; tomada de decisão; elaboração de políticas; avaliação de tecnologia.

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List of acronyms

BEV – Battery electric vehicle

CEIIA – Centro de Excelência e Inovação para a Indústria Automóvel

CEO – Chief Executive Officer

CI1 to CI4 – Complementary Interviews

CO_2 – Carbon dioxide

EDP – Energias De Portugal SA

EIS – European Innovation Scoreboard

EMobi – Electric mobility case

EU – European Union

Eurostat – Statistical Office of the European Commission

EV – Electric Vehicle

GDP – Gross Domestic Product

I1to I26 – Interviews

ICE – Internal Combustion Engine

ICT – Information and Communications Technology

ILO – International Labour Organization

i-MiEV – Mitsubishi innovative Electric Vehicle

IRR – Internal Return Rate

MRI – Magnetic resonance imaging

NanoLab – Nanotechnology laboratory case

NIS – National Innovation System

OCDE – Organisation for Economic Co-operation and Development

OEM – Original equipment manufacturer

PI1 to PI12 – Preliminary Interviews

R&D – Research and Development

R&D&I – Research and Development and Innovation

S&T – Science and Technology

STI – Science and Technology Indicators

TA – Technology Assessment

TPP – Technological Product and Process

UNDP – United Nations Development Programme

UNESCO –United Nations Educational, Scientific and Cultural Organization

USA – United States of America

VLA – Net Present Value

WHO – World Health Organization

1. INTRODUCTION

Indicators exist as a human effort to simplify understanding and governance of reality. They are conceptual instruments used to measure, evaluate and help with decisions by summarizing characteristics or highlighting what is happening in reality. Their use in human history can be traced back to fourteenth century historical records regarding the management of the Venetian sugar trade with Cyprus (Maddison 2001). Later, the rise of science played an important role in stimulating the need for quantification through an emphasis on objectivity, the written word, rigor, precision and transparency (Shor 2008). More recently, and particularly since the 1930s, the use of indicators increased with the intensification of science and the emergence of a real culture of objectivity. In the 1970s, the “social indicators movement” was born in reaction to the economic alignment of this quantification culture. Since then, the use of indicators as a way of reasoning has spread to several areas of knowledge and human endeavour. In fact, they can be seen in the management of companies, administration of states, military works, healthcare, scientific production, and accounting, among others (Fioramonti 2014; Porter 1995; Power 1997). Presently, there are thousands of indicators alone in the area of social sciences (Fioramonti 2014), and many more can be found in other fields to support understanding and governance of modern societies.

Despite the proliferation of indicators, research about their real influence in decisions received less attention. Most literature aims to develop, analyse or evaluate them. Only a limited set of works studied their influence in decision-making (MacRae 1985, Gudmundsson and Sørensen 2012, Sébastien and Bauler 2013; Lehtonen 2013). In fact, the role of indicators remains almost enigmatic because little is known about how they are used in decision-making (Sébastien and Bauler 2013). Furthermore, research about the role of indicators in innovation contexts is rather limited and recent. Only recently have two studies provided evidence about the role of indicators in policy decisions related to sustainable development (Gudmundsson and Sørensen 2012; Sébastien and Bauler 2013). Until now, little is known in relation to other innovation areas and actors.

This gap in the innovation literature can be problematic for four main reasons. First, the role of indicators in innovation is important to understand how decisions are made and actors behave. In fact, literature should identify the ways indicators are included in the decision and, at the same time, capture the behaviour of different decision makers when using them. More knowledge of about the use of indicators is also important in innovation policies because they are intended to act upon the innovation system, changing the environment where private and public researchers develop their innovations. Additionally, innovation policies have obvious implications for socio-economic growth and development through action upon the socio-economic system, where innovations can interact and promote economic growth. Moreover, existing knowledge about the influence of indicators in sustainable policy is not enough to allow generalizations in other areas of innovation and actors of the innovation system. Therefore, there is the need for more research to enable a discerned use of indicators and to improve actions upon the innovation system.

This gap in the literature is also problematic to technology assessment studies for several reasons. First, technology assessment frequently relies on indicators to address relevant societal questions about technology (Barré 2001). For example, in a technology assessment study about the potential and impacts of cloud computing services, Leimbach et al. (2014) used indicators about the type of use and the type of cloud services in order to understand and explain the adoption and usage patterns of companies and consumers. Second, indicators are not neutral instruments to analyse technology problems, because they are selected by criteria that express values and interests of those who propose a specific description of a problem. For example, it is significantly different to observe an indicator of a CO_2 footprint of a product than to analyse the whole chain of different risk factors associated with the use of a technology. Third, the description of complex problems and the strategies for their solution are heavily influenced by the use of indicators. For example, the use of an indicator of "security of livelihood" in a sustainability problem introduces a specific description of a selected problem, which is in this way placed as a key problem against which strategies for its solution are to be defined. Fourth, technology assessment needs a transparent and thoughtful relation with indicators because it can not only lead to new alternative technology options, but also create space for controversies between stakeholders that use a limited set of indicators. For example, the debate about risks of nuclear power plants shifted in the moment the indicator of climate neutrality came in, because nuclear fission previously seemed to be an environmentally friendly technology. Fifth, the applicability of indicators used and proven in established fields needs reflection while transferring them to a new or emergent technology, as conditions can change significantly and there might be changes in methodology or new empirical test settings relevant for uncover possible harm or damage. Sixth and last, the study of how indicators are involved in policy-making can help technology assessment practitioners to understand the policy process. This can also help to differentiate from the scientific and business processes, to develop public participation practices and to improve scientific communication of findings. These insights about the policy process can also help to identify stakeholders that influence the decisions, as well as to determine their role in the decision process. In essence, the knowledge gap is problematic to technology assessment because studies frequently rely on indicators, the selection of indicators is not neutral, they can open alternatives and controversies, and their study can improve knowledge about policy processes.

This work addresses this knowledge gap with research designed to understand three questions: what is the extent of the influence of indicators in technology innovation decisions? What is the role of indicators in these decisions? And how are indicators used in these decisions? It will be argued that the extensive use of indicators is different from their real influence on decisions, and that indicators play mostly a minor role, explainable by the type and phase of the decision, and the context and the process of construction of evidence. Results will also describe the behaviour of the actors and their relationships in policy decisions. In sum, answers to the three research questions will provide new findings to the literature about indicators in decisions of technology innovation.

The research questions focused specifically on three groups of actors and four types of decisions. First, the work dealt with three Portuguese technology innovation groups that significantly invested in technology innovation. These groups are: a research group composed of public researchers and academics; a business group comprised of leaders of research, development and innovation departments in companies; and policymakers related to technology innovation. Second, research concentrated on the four types of decisions of technology innovation, namely: acquisition of equipment or a specific technology; development of a product or a specific technology; purchase of property rights; and design of policies (e.g. programs, measures, actions and projects).

There was one noteworthy difficulty in conducting this research. The variety of definitions of indicators is significant (Heink and Kowarik 2010), making it difficult to frame the object of analysis across innovation groups and sectors. On one hand, indicators may be selected to characterize the efforts undertaken by countries/regions/companies. They usually cover resources devoted to research and development (R&D), innovation, patenting, technology balance of payments, international trade in R&D-intensive industries, etc. For example, the publication "Innovation Union Scoreboard" uses three indicators to measure the availability of a highly-skilled and educated workforce: "New doctorate graduates"; "Population aged 30-34 with completed tertiary education"; and "Population aged 20-24 having completed at least upper secondary education" (Hollanders and Es-Sadki 2014). On the other hand, in a laboratory or innovation department context, indicators often reflect the applied nature of innovation. For example, innovation indicators in a business context can be related to the energy consumption of manufacturing a product, the cost of a machine to improve a process, or the amount of raw material introduced in a new technology. Furthermore, sometimes indicators are defined as a concept (e.g. climate neutrality), and in other cases they consist of measures of a phenomenon (e.g. population aged 30-34 with a completed tertiary education). Therefore, there was the need to adopt a definition of indicators broad enough to encompass the meanings they can have in different innovation activities.

The present work contains four more chapters. The following chapter presents the theoretical framework underpinning this research in two different blocks. The first subchapter discusses the role of evidence and indicators in decision-making. It first examines the use of evidence in decision contexts, and the emergence of a movement calling for their introduction in public policy. Afterwards, it addresses the difficulties in framing a definition of indicators, the rise of quantification in human reasoning and the main merits and limitations of indicators. Last, it discusses the existing knowledge about indicators' use, influence and role in the decision process, and presents a proposal to address the gaps found in the literature about indicators in technology innovation. Furthermore, the second subchapter develops the main concepts associated with the decision process of technology innovation. It starts by introducing concepts related to innovation, namely the process of innovation, its main actors, the networks they form to innovate, and the main concepts of innovation policy. It also introduces the reader to the theory of the decision process, presenting a model to interpret decisions of technology innovation and the main factors influencing these decisions. Afterwards, it describes the four types of decisions of technology innovation, which often occur embedded in elements of complexity and uncertainty.

The third chapter describes the methods used to test the hypotheses. It first describes the methodological choices made. It also concentrates on presenting the various methods used: surveys (with self-administered questionnaires and standardized interviews); and case studies of a decision related to electric mobility and a decision to create a laboratory of nanotechnology. The networks created to make these two latter decisions were also analysed using social network analysis. In the last phase, the work included complementary in-depth interviews with experts to answer remaining questions.

The fourth chapter presents the main results in three blocks that address the research questions. The first subchapter describes the extent of the use and influence of indicators in technology innovation decisions, based on results from the survey. The second subchapter presents results to characterize the role of indicators in these decisions. The third and last subchapter presents results to explain how indicators were used in these decisions. It combines results from the survey and the case studies to test whether the type and phase of the decision, and the context and the process of construction of evidence, are factors affecting the way indicators are introduced in decisions.

In the last chapter, the main conclusions of the thesis are described. The conclusions are also discussed in relation to the existing literature to establish the contributions of this work. Afterwards, an overview of the limitations of this thesis and possibilities for future work are discussed.

2. THEORETICAL FRAMEWORK

This chapter introduces the theoretical framework to study the role of indicators in the decision process of technology innovation. The first subchapter argues that more research is needed about the role of indicators in these decisions. The second subchapter develops the main concepts needed to conduct research into the decision process of technology innovation. The third and last subchapter summarizes research questions and hypotheses, and identifies the main concepts to be used in this research.

2.1 EVIDENCE AND INDICATORS

This subchapter argues that there is a gap in the literature of innovation and technology assessment, thus requiring research into the influence and the role of indicators in decision-making. The discussion will show the need for comprehensive information about the extent of the use and influence of indicators in decisions of technology innovation, their role in these decisions, and the way indicators are involved in decisions. Furthermore, the subchapter is divided into four sections: the first section examines the use of general evidence in the decision-making process; the second section discusses the historical emergence of quantification in society; the third section describes the main merits and limitations associated with indicators in decision-making; and the fourth section identifies a gap in the literature of innovation and technology assessment in relation to the way indicators are involved in decision-making. This last section proposes a process to clarify the extent of the use and influence of indicators in these decisions, the role of indicators and how indicators are used in decisions of technology innovation.

2.1.1 The use of evidence

"Evidence" can be operationally defined as the available body of facts or information indicating whether a belief or proposition is true or valid[1]. It follows that the truthfulness or validity of a proposition depends on the strength of the evidence: weak evidence does not exclude other contradictory assertions; and strong evidence normally excludes contradictions and typically agrees with scientific findings[2]. Furthermore, evidence can assume various forms in different contexts. In fact, evidence can be indicators, historical facts, statistics[3], results of experiments, texts, quotes from secondary sources, real experiences or histories, or opinions of individuals in one field. These forms can also vary with the context: In policy-making contexts, evidence can range from numerical data to

[1] "Evidence" Oxford Dictionary Online. Last accessed in 21/12/2014. http://www.oxforddictionaries.com/de/definition/englisch/evidence.

[2] Scientific findings are qualitative and quantitative research findings produced and tested by means of Science and Technology (S&T).

[3] For the purpose of this work a statistic is a numerical fact or datum, especially one computed from a sample (Gault 2013b).

ethical/moral interpretations expressing values, attitudes and perceptions of stakeholders and other decision makers. In health contexts, evidence can be research findings, other knowledge that is explicit, systemic and replicable, or simple acceptable waiting times (Lomas et al. 2005). In management contexts, evidence can include costs, technical characteristics of materials, stakeholders' opinions, etc. In sum, *evidence* is the body of facts or information that supports the strength of a proposition, and can assume various forms depending on the contexts where they are considered.

There is an abundance of uses for "evidence" in policy literature. In one extreme, evidence can be strictly identified with scientific outputs. In this case, evidence comprises all types of science (and social science) knowledge generated by research and analysis processes, either within or without the policy-making institution (Juntti, Russel, and Turnpenny 2009). On the other end of the spectrum, evidence is considered useful to support policy. In this case, evidence is not necessarily data or information, but mostly a selection of the available information introduced in an argument to persuade of the truthfulness or falseness of a statement (Flitcroft et al. 2011). Furthermore, the use of evidence in policy-making can be a subjective process. In fact, the strength and quality of evidence can be related to the number of controversies it experiences during its lifetime (Sébastien and Bauler 2013). In these cases, evidence loses strength in the decision-making process with any increase of controversy since creation. In addition, the selection of evidence can depend on the situations in which policymakers find themselves. These situations shape which information is used from the complex set available, and which evidence is rejected or at least downplayed (Perri 6 2002). In fact, policy-making "always makes use of some evidence, but there is a plurality […] of things that count as evidence, and what counts depends on where policymakers are situated" (Perri 6 2002, 7). Moreover, the selection of evidence can be related to epistemological choices of the decision maker, in terms of claims about valid sources of knowledge and how to judge knowledge claims. These choices can be related to the use of quantitative or qualitative information, but also ideology, as, for example, religious believers might endorse theological claims to knowledge. These choices often reflect ontological assumptions about the objectivity or subjectivity of reality. For example, for some, only positivistic techniques of inquiry support claims to knowledge as reliable facts, whereas for others the complexities of the social world demand an interpretation of human behaviour and intentions (Henn, Weinstein, and Foard 2009) In this context, policy emerges from the interaction of different forms of evidence, filtered and shaped by the institutional processes of decision-making (Flitcroft et al. 2011, 1039).[4] This filtering process is subjective and one piece of evidence can be chosen instead of another, leading the argument in different directions.[5] Therefore, what counts as evidence in policy-making can vary from "pure"

[4] To the authors, policy-making is the management of rival value set and notions of evidence.
[5] The political system has social procedures to relativize criticisms, rejections, risks and failures associated with policies. According to Niklas Luhmann:
"The daily struggle between government and opposition makes all causal constructions of origin and result controversial anyway. There are always people around who criticize decisions. This noise, to which politicians are accustomed and on which they thrive, makes the prospect of post-decisional regret a normal fact of life that has to do with the essence of politics, and not with the content or merit of a particular decision. The important

scientific outputs to selected information used to create an argument, depends on the controversies associated, can vary with the context of the policymaker and is subject to a complex filtering process.

The use of evidence in policy-making practice is poorly studied. In fact, there is a significant body of literature about why and how scientifically based evidence should be used by decision makers. However, a much smaller set of recent studies examines the direct use of evidence in policy-making practice (Hall and Jennings 2010). In a work about the use and weight of information and evidence in U.S. state policy decisions, the authors stated:

> We know very little about where agencies seek information, and how they weight information from various sources in their decision process. And within that sphere, the prevalence of formal scientific evidence use in policy decision remains somewhat a mystery. (Hall and Jennings 2010, 137)

Furthermore, there are increasing calls for public policies that use evidence (Head 2010; Flitcroft et al. 2011; Juntti, Russel, and Turnpenny 2009; Sorrell 2007; Hall and Jennings 2010). These calls are based on the idea that the inclusion of evidence leads to the best-informed decisions possible. According to C. Porter (2010), evidence-based policy-making is a worthy aspiration that improves the quality of decision-making. It is based on the idea that knowledge can be disseminated in the policy process through the introduction of scientific facts, concepts and theoretical perspectives (Weiss 1979). In addition, evidence-based policy is particularly attractive in countries with a political culture of transparency and rationality in the policy process, and with a research culture committed to rigorous methodologies using policy-relevant evidence (Head 2010). In sum, there are increasing calls for transparent, rational and rigorous introduction of evidence in policies based on the best available scientific knowledge, despite the fact that the extent of their use in practice is poorly understood.

These calls for policies that include evidence are coming from professionals in different fields. First, the calls probably originated in healthcare practitioners demanding policies based on the best evidence-based practices. A major challenge has been to translate the findings and lessons of healthcare research about effective treatment into clinical guidelines to be used by healthcare professionals (Head 2010). After, management literature called for an increase in the use of evidence at least in making important decisions (Jauch and Glueck 1988; Head 2010). Head (2010, 79) argued that business leaders are dependent on accurate evidence about performance, standards and market conditions, and that decisions should increasingly be based on reliable information and expert dialogues, rather than on power and personal intuition. A similar trend can be found in the field of

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thing is to remain accepted within your own power network. Hence, politicians become inured to daily criticism and rejection; the predominant question is from which side it comes. They develop rhetorical techniques and network-repairing devices in order to survive, and the causal network is complex enough to provide for divergent attributions. […] Politics has a high institutional […] capacity for absorbing risks. It dissolves risks into noise and news. But if we continue to expect a political solution to the larger problems of modern society we will be disappointed. The political system appears as a collective actor. It is the prime addressee for all kinds of problems which find no solution elsewhere". (Luhmann 1990, 229).

(social) development (see among others C. Porter 2010). Some authors have even named these groups an evidence-based movement (Glasner-Edwards and Rawson 2010; Jonson-Reid 2011; Denzin 2009; Lilienfeld et al. 2013). Therefore, there is an "evidence-based movement" from professionals in different fields arguing for decisions based on the best available evidence.

This evidence-based push can also be identified in Science, Technology and Innovation (STI) policy. In fact, there are signs that in Europe STI policies are increasingly being based on evidence-based policy, rather than on rationale informed by systemic models of innovation and from economic theories of knowledge and technical change. In 2002, the adherence of the European Council to one explicit target based on an indicator symbolizes this shift towards policies based on evidence (Moniz 2011). In fact, all European countries agreed to increase the overall spending on R&D and innovation to approach 3% of GDP by 2010, with two-thirds of this investment coming from the private sector.[6] Furthermore, the two main determinants of this push in evidence in STI policy are the increasingly large sums of public funding to R&D at European and national levels, and the ease of access to computer-based data collection (Godin 2009a). For example, the European Commission publishes the yearly Innovation Union Scoreboard for free and for more than a decade. The publication gathers evidence for systematic comparison of innovation performance across European countries/regions and promotes international policy benchmarking. In another example, both PRO INNO Europe and ERA Watch[7] programmes systematically collect and freely diffuse data, evidence, policies and programmes on European, national and regional levels. In addition, there is also a growing demand for evidence from private businesses, consultants and policy advisors (Mytelka and Smith 2002; Godin 2009b). Last, several technology assessment[8] reports revealed the need to enhance existing evidence to base forecasts on the impacts of future technology developments (Grunwald 2007; Europäische Akademie 2004). In sum, there are signs that STI decisions are increasingly being based on evidence, driven by different stakeholders of the innovation system[9].

There are some disagreements with this evidence-based movement, despite their growing popularity in some countries. The first line of criticism is related to the quality of the evidence, because the explanatory scope of most evidence is often more limited than its use in policy decisions. Hall and Jennings (2010, 139) argued that information of dubious reliability or validity may be used to justify public programs. This line of criticism can also include evidence being used for rhetorical purposes, while adopting policies that may not adequately utilize the evidence that is available or obtainable. The second line of criticism is epistemological and relates to the overreliance on quantitative studies for evidence-based policies. Despite the limitations of quantitative findings,

[6] European Council. 2002. "Conclusions of the Barcelona European Council 2002." Vol. 35. Barcelona. Last accessed in 11/12/2014: http://ec.europa.eu/invest-in-research/pdf/download_en/barcelona_european_council.pdf.

[7] More information about these two programmes can be found respectively at: http://grips.proinno-europe.eu/about/ and in: http://erawatch.jrc.ec.europa.eu/

[8] The concept of technology assessment will be developed in the subchapter 2.2.

[9] The concept of innovation system will be developed in the subchapter 2.2.

qualitative research continues to play a small role in circles of evidence-based policy. In fact, qualitative findings remain accepted only to provide nuances to most quantitative studies (Veltri, Lim, and Miller 2014).[10] A third line of criticism relates to the lack of research supporting the claim that, for example, evidence-based management leads to real improvements. In management studies, evidence-based supporters "simply restate the dominant discourse and make unsubstantiated claims that there is an evidence base without producing the actual evidence" (Stacey 2011, 180). Therefore, although growing in popularity, the use of evidence in policy-making still faces relevant criticism.

2.1.2 The rise of quantification

There is a significant number of types and definitions of indicators (Heink and Kowarik 2010). These varieties challenge the framing of analysis both in an innovation[11] policy context and in a laboratory. First, in innovation policy contexts, indicators are commonly understood as variables selected to characterize the efforts undertaken by countries/regions/companies in the field of science, technology and innovation. These indicators measure resources devoted to research and development (R&D), innovation, patenting, technology balance of payments, international trade in R&D-intensive industries, etc. There is a significant amount of innovation indicators freely available for comparisons over time and across countries, regions, sectors and companies.[12] For example, the Innovation Union Scoreboard captures the economic success of innovation using five indicators: "Employment in knowledge-intensive activities", "Contribution of medium and high-tech product exports to the trade balance", "Exports of knowledge-intensive services", "Sales due to innovation activities", and "License and patent revenues from selling technologies abroad" (Hollanders and Es-Sadki 2014). Second, in a laboratory or innovation department context indicators often reflect the applied nature of innovation. For example, in a business environment, innovation indicators can be related to the energy consumption to manufacture a product, the cost of a machine to improve a process, or the amount of raw material introduced in a new technology, as mentioned. In addition, definitions are bound to the level of analysis of indicators. In fact, sometimes indicators are defined as a concept (e.g. climate neutrality and human toxicity), and other times they consist of measures of a phenomenon (e.g. population aged 30-34 with a completed tertiary education and gross domestic expenditures on R&D).

[10] According to Veltri, Lim, and Miller (2014), qualitative findings can contribute to evidence-based policy in different ways. First, qualitative research offers a commitment to observe and explain phenomena from the perspective of those being studied, providing them with a "voice". Second, this type of research provides reflexive awareness and consideration of the researcher's role and perspective. Third, the authors argued that qualitative research is not methodologically orthodox and can use flexible research strategies. Fourth, qualitative research offers a contextualization of the data collection and of its analysis. Fifth, qualitative research is thoughtful of emerging categories and theories rather than relying upon a priori concepts and ideas.

[11] The concepts of innovation will be developed in the subchapter 2.2

[12] Indicators are systematically published and downloadable from most public institution working with innovation policy (e.g. OECD, the European Commission, Eurostat, national statistical institutes and UNESCO). There are also many official publications, such as Main Science and Technology Indicators, Innovation Union Scoreboard, and EU Industrial R&D Investment Scoreboard.

Therefore, the variety of types and definitions of indicators suggest adoption of a definition broad enough to include all indicators used to make decisions of technology innovation[13].

Indicators can be defined as conceptual instruments used to measure, evaluate and help with decisions by summarizing characteristics or highlighting what is happening in reality. In this context, an indicator is an instrument to support decisions related to equipment, a product, a process, a technology, a patent or an innovation system. Indicators are often a compromise between scientific accuracy and the information available at a reasonable cost. Furthermore, the definition of indicator can also include qualitative indicators such as certifications, submissions and other categories, as well as other more subjective measures such as satisfaction, worries or trust (Rammstedt 2009). Nevertheless, indicators are frequently based on quantitative measures that can be linked to the emergence of objectivity in human reasoning.

Indicators exist as a human effort to simplify the understanding and governance of the realm. They are inherently connected with the social need of quantification[14] for public as well as for scientific purposes. The sociologist Max Weber emphasized the rise of capitalism and the rational spirit in western societies to explain a move towards a more rational, bureaucratic and calculative life, and the increased tendency to quantify social entities and behaviours (Shor 2008). Theodore Porter (1995, 74) argued that these quantification efforts were generally allied with the raise of the "spirit of rigor". According to the author:

> Strict quantification, through measurement, counting, and calculation, is among the most credible strategies for rendering nature or society objective. It has enjoyed widespread and growing authority in Europe and America for about two centuries. In natural science its reign began still earlier. It has also been strenuously opposed. This ideal of objectivity is a political as well as a scientific one. Objectivity means the rule of law, not of men. It implies the subordination of personal interests and prejudices to public standards. (Porter 1995, 75)

Furthermore, other explanations about the proliferation of quantification can be found in the rise of the modern centralized state. In fact, in France and the USA in particular, public officials faced the need to efficiently manage increasing populations and large-scale social institutions (Shor 2008). In this context, strategies of impersonality drove the transition to more explicit decision criteria (i.e. objective decisions) in public governance, instead of the old practice of expert judgment (subjective decisions) (Porter 1995). The rise of objective decisions appears to be linked more to external pressures to use explicit criteria, than to the need for better decisions arising from powerful insiders interested in better decisions, according to the author. In addition, Power (1997) suggested that accountants and the rise of bureaucracy also played a significant role spurring the growth of quantification, particularly during the

[13] The concepts of decision-making and of technology innovation will be developed in subchapter 2.2.

[14] Quantification is the act of giving a numerical value to a measurement of something, that is, to count the quanta of whatever one is measuring, producing a standardized form of measurement that allows statistical procedures and mathematical calculations (Shor 2008).

twentieth century. In sum, the rise of indicators is connected to the emergence of quantification efforts that resulted from rationalization practices, scientific thinking, social need to produce impersonal and explicit decisions, and the rise of accountants and bureaucracy in society.

The origins of indicators as modes of knowledge and governance are difficult to trace back in history. In the fourteen century, indicators related to the size and carrying capacity of galleys were used to control and manage the sugar trade between Venetia and Cyprus (Maddison 2001). Later, the rise of the scientific mentality played an important role, as mentioned before, by stimulating the need for objectivity, the written word, rigorous quantification, precision and transparency. For a long time, the quantification efforts of science remained associated with the practical world of administration and commerce. For example, although in 1648 Pascal discovered that a barometer's mercury would fall when carried to a higher elevation, it was only in eighteenth-century that military engineers developed rigorous barometric measurements of land elevation to draw topographical maps of mountainous regions (Porter 1995). During this time "the art of reasoning by figures on things relating to government" was called political arithmetic (Maddison 2003, 15). Afterwards, indicators were used in connection with the raise of the modern nation-state in the beginning of the nineteenth century, and their need to govern objectively, impartially and transparently (Merry 2011). In fact, an increase in demands for indicators came from the need of engineers and technocrats enrolled in the development of administrative culture in modern France. These groups were highly interested in administrative management, and had considerable enthusiasm for the work on efficiency by Frederick Winslow Taylor, among other managerial writers (Moniz 2007; Porter 1995).

In the 1930s, a significant emphasis was placed on quantification with the growth of science in the USA and the culture of equidistance and impersonal objectivity in decision-making. In the US, important efforts of quantification were implemented with the systematic use of Intelligence Quotient[15] tests to classify students, opinion polls to quantify the public mood, elaborate statistical methodologies for licensing drugs, and even cost-benefit and risk analyses to assess public works (Porter 1995). Later in the 1950s, a significant stimulus was given to the need of objectivity and quantification by the US Corps of Engineers, concentrating their "failed engineers" in economic activities around all district offices "where they were likely to do less harm" (186). At the same time, the US Corps began employing increasing numbers of economists and other social scientists. This resulted in a takeover of economists and the emergence of cost-benefit analysis in modern economic studies, according to the author. This type of analysis began with water projects and transport studies (Scigliano 2002), but were later significantly disseminated by Rand's[16] military studies.

[15]Intelligence Quotient, commonly known as IQ, is a score derived from standardized tests designed to assess intelligence.

[16]According to Linstone (2008) the Rand Corporation is the most influential American think-tank of the second half of the twentieth century. The company was established in 1946 to deal with useful applications labelled "operations research", which applied mathematics to problems such as interceptor vectoring and convoy protection. Presently, Rand is well accepted in decision-making corridors of Washington, DC, and offers vast

In the 1970s, a “social indicators movement” was born in reaction to the economic orientation of the above-mentioned quantification culture (Land 2000). A group of intellectuals, mostly social scientists, considered the word “social” to be restrictively defined and meant only “outside the realm of economics” (Sheldon and Parke 1975, 695). According to this group, science (or quantification in general) created a new sort of “philistines” encouraged by the relative ease of expressing quantities in dollars and, consequently, giving an exaggerated importance to these numbers in the interpretation of reality (695). Therefore, scientists linked to this movement argued for a change in conceptual frameworks, shifting the emphasis from economics to measures of social change, which included different subsystems in society like education, health, economics, etc. The arguments were focused on the controversy that resulted from an economic-centred perspective, and mainly concentrated on what this new wave of indicators should measure.

The controversy eventually faded-out and the quantification rationale started to be applied to several parts of life, broadening its scope to many areas of knowledge and human endeavour. Presently, it is possible to find this quantification rationale applied to global scales (Misuraca, Codagnone, and Rossel 2013; Maddison 2001) and even in our personal lives. For example, Robichaud, Durand, and Ouellet (2006) reported on the existence of indicators for personal quality of life, such as measures of verbal communication interaction, well-being, participation level in social activities or engagement and integration in the community. Furthermore, this new quantification trend should not be interpreted as an attempt against qualitative methods of reasoning. In fact, the production of a quantitative indicator primarily reflects values of an ethical, moral, political, economic or financial nature existing in society before their creation. Their significant expansion in recent years was based on an existent societal will expressed, for example, by many influential organizations (e.g. OECD[17], ILO[18], UNDP[19], WHO[20] and universities). Despite its problems, quantification is an important and viable component of today’s social world, and there are few who would argue for returning to a pre-quantification world (Shor 2008).

2.1.3 Merits and limitations of indicators

Indicators are commonly understood as containing knowledge that can be used. At the individual level, an actor positions him/herself personally in relation to an indicator after having read, digested and interpreted the knowledge it contains; at the collective level, the use of indicators is part of an organisation’s operational routines with stabilised ways of thinking and acting about knowledge (Sébastien and Bauler 2013). Technology decisions[21], in particular, can be supported by the use of

research and analysis to the U.S. armed forces. Rand is currently financed by the U.S. government and private foundations, corporations including the healthcare industry, universities and private individuals.

[17] OCDE is the acronym of the Organisation for Economic Co-operation and Development.

[18] ILO is the acronym of the International Labour Organization.

[19] UNDP is the acronym of the United Nations Development Programme.

[20] WHO is the acronym of World Health Organization.

[21] The concept of technology decisions will be developed in subchapter 2.2.

indicators at least theoretically, since indicators are seen as containing knowledge to help the decision maker achieve a more efficient decision. For example, the use of the number of graduates in S&T is a commonly used indicator when deciding about innovation policies. In fact, the indicator can help understand the amount of available scientific skills in the labour force when facing a policy decision. In another example, the use of the financial cost of energy in a factory is an accepted indicator to decide about the acquisition of wind turbines for an industrial plant. Therefore, many of our perceptions about innovation[22] can be informed by this type of quantitative knowledge (Katz 2006). Furthermore, the repetition of these measures enables the establishment of monitoring systems. In fact, agencies such as the OECD, Eurostat[23], UNESCO[24] and the American National Science Board collect measures related, for example, to population, GDP[25], Gross Expenditures on R&D and numbers of scientific papers and citations. The ratios between these measures are used as performance indicators such as national wealth (GDP per capita), Business R&D intensity (BERD/GDP) and scientific impact (citations/paper). In the end, these measures, combined with a set of performance criteria, can be used to evaluate programmes and projects and in benchmarking exercises. With these measures the state of a system is compared with a desired future state or another comparable system (e.g. country and region) (Gault 2010). Last, indicators (preferably disaggregated) can also be used to provide background support to foresight exercises. In sum, indicators are an accepted instrument of useful knowledge that can help to make different types of social, scientific and technological decisions.

Literature about indicators also includes four arguments about their usefulness in decision-making. First, indicators can lead to better decisions and more effective actions by simplifying, clarifying and making aggregated information available to decision makers (United Nations 2007). For example, when taken as a system, they can guide experts and society in vast and complex issues, such as urban quality of life and sustainable development (Feller-Länzlinger et al. 2010). Second, indicators can be reference tools for social thinking and can useful in communicating ideas, thoughts and values. In fact, they can help to measure and calibrate progress towards societal goals, and provide an early warning to prevent economic, social and environmental setbacks (United Nations 2007). Innovation indicators were described as a “technology” selected by consensus, produced by institutional or individual users, and governed by a set of rules in manuals that guide the collection and interpretation of data for international comparisons (Gault 2013). Third, the systematic use of indicators can introduce knowledge in decisions. In fact, when used to shed light about phenomena, indicators can facilitate the incorporation of physical and social science knowledge into decision-making (United Nations 2007). Fourth, indicators are inherently connected with the need to make less controversial decisions. In fact, many believe that quantification minimizes prejudice, favouritism and nepotism in decision-making (Shor 2008). In short, arguments for the usefulness of indicators in decision-making

[22] The concept of innovation system will be developed in subchapter 2.2.
[23] Statistical Office of the European Commission.
[24] United Nations Educational, Scientific and Cultural Organization.
[25] Gross domestic product.

include better decisions, more social thinking and introduction of knowledge and consensus in the decision process.

However, despite their merits, there are also a number of limitations associated with indicators. These limitations can be divided into five different types of problems:

- One of the main problems with indicators is related to the variety found in their definitions, as previously mentioned. The variety is significantly contingent upon the topic and objective of the study in question. For example, Heink and Kowarik (2010) revealed that other authors in the same specific field of ecology and environment had often used different definitions and different indicators. The variations found under the definition of ecology and environmental indicators were significantly dependent on the topic under observation, the objective and the intended final user (e.g. politicians, researchers, companies, experts, general public and media). The authors also pointed out that none of the available definitions of indicators could completely cover the variety of concepts the term can have within the ecology and environment arena. Furthermore, the variety of possible typologies to study indicators is significant. In general, the categories are linked to the objectives of each study. There are three relevant examples of a distinction between different objectives of the works and typologies created. First, in an environmental work, Smeets and Weterings (1999) classified indicators into four groups: a descriptive group (where indicators address what is happening), a performance group (where they answer whether it is relevant), an efficiency group (where they show if there are improvements), and a composite indicators group (where the aggregation of several indicators show if the overall situation is better). Second, Heink and Kowarik (2010), in a study dedicated to understanding differences in ecological indicators, found indicators classified as descriptive measures, normative measures, hybrid measures, parameter values, measurements or measurement of results on hybrid concepts, descriptive components and hybrid components. Third and last, in a study about global governance by indicators, K. Davis, Kingsbury, and Merry (2012) defined two categories wherein indicators were used for evaluation and judgment. In sum, the variety of typologies created to classify indicators is significantly diverse, and related to the objective of each study. Therefore, it is difficult to find a common definition and typology to classify indicators.
- The second order of problems of indicators is related to the general effects of their use. There are six types of general effects:
    1. Measurements to construct indicators may produce fatigue in respondents (Power 1997). They may also change the object of measurement given that once something is measured it changes its characteristics.
    2. Indicators may give rise to resistance when perceived as a threat or seen as a cause for social, economic or ecological instability or even damage. For example, indicators can provoke resistance

when they are set up to control or monitor[26] controversial labour or economic issues (e.g. working hours and sectoral productivity related to pay raise). In another example, if respondents to surveys fear their answers will be used against them or threaten their status quo, individuals may try to bias their responses.

3. Indicators can suffer from excessive use, pressures deriving from material and organisational interests, and clashes of basic values and ideologies subject to political conflict (e.g. general orientations towards government, the state, quality of life, morality and inequality) (MacRae 1985).

4. Indicators can be subject to political influence. In fact, if an organisation or a profession is a constituency of either the collector or reporter of the data, it can be expected to exert the same kind of influence as if they were directly handling the data themselves (MacRae 1985). In some cases, indicators can suffer from confidentiality problems or even the public's suspicion of violations of privacy, according to the author. Apart from the threat of direct (i.e. governmental) manipulation, there is also the danger that rigid governmental rule by an indicator may undermine political debate (indicators can precipitately justify measures by bypassing a broad public debate), and prevent reinterpretations of the world (when a problem does not exist anymore).

5. The development of indicators impacts its users. In fact, indicators are a "technology" which governs behaviour, is modified by users (outside the producer community), and develops in response to the user's needs (Gault 2011). Some types of indicators were developed to address a perceived need of a community that wants to use them, and is influenced by them in two major ways: Firstly, the development and evolution of an indicator involves consensus-building activities and the establishment of a common language to construct a discourse (with an agreed vocabulary and grammar) (Gault 2011). These activities impact the practitioners as they learn to use the language and advance the subject at hand. Secondly, after the development phase, the use of language and feedback from users also has an impact on society (Gault 2011). As a result of using indicators, users may change their behaviour or provide suggestions for later revision of indicators.

6. Indicators can create a reality that is put on stage, fixing and restricting the way the world can be defined. In fact, indicators can have a subliminal effect, setting fixing pathways for society through their use that sets political effects in motion. For example, the concept of scientific activity in bibliometry[27] is sometimes defined exclusively in terms of publications undermining other important activities. By focusing on an indicator of research output, a view is enhanced where scientific activity is similar to industrial production and other important activities are not

[26] Monitoring is an activity involving repeated observation, according to a predetermined schedule, of one or more elements of the environment to detect their characteristics (status and trends) (United Nations Environment Programme 2010).
[27] See van Raan (1993).

accounted, such as scientific inquiry, reading, collecting data, serving as an editor or reviewer, giving advice or engaging in debates (Dahler-Larsen 2013). Furthermore, indicators can produce constitutive effects on reality. In fact, an indicator has an interactive constitutive relation with the reality it seeks to describe, and is not a neutral representation of an existing concept, according to the author. An indicator helps define the concept it claims to measure in an operational way, similar to how intelligence tests contribute to define our concept of intelligence. In addition, there are three main mechanisms through which indicators can lead to constitutive effects of reality: indicators can create organizational procedures which structure an otherwise messy reality; indicators can shape language, establishing particular meanings, definitions, incentives and regulations in which professionals and lay people have to respond; indicators also enforce institutional lock-ins with incentives and sanctions, rewarding pushes for standards, norms and procedures in affected groups, according to the author. An observable case of these constitutive effects are the publishing of school rankings: A type of school quality is created through the actions (e.g. reactions to position in the league) and interactions between the actors in schools that follow the publication of school rankings (Dahler-Larsen 2013, 15). An unintended effect of the rankings is to create a reality where the concept of quality is oriented towards competitiveness rather than to the inclusion needs of some schools.

In sum, the use of indicators can produce general effects (e.g. fatigue, resistance, pressures and clashes), be subject to political influence, impact users, and be a straitjacket to parts of society.

- The third order of problems of indicators is related to the consequences of their systematic use. Indicators can impose a moral and ethical behaviour through the silent assimilation of their implicit values and duties into society (Merry 2011). In fact, the repetition of a prescription encoded in an mechanism (in this case an indicator) can, in the long run, change established values and patterns of thought (Latour 1992). Some examples of these effects can be found in the systematic use of innovation rankings, school rankings, New Public Management prescriptions, the European Commission's excessive deficit procedure[28], etc (Dahler-Larsen 2013). Furthermore, the systematic repetition of an indicator can contribute to the establishment of the view of the world embedded in its definition (Dahler-Larsen 2013). For example, an indicator emphasizing consumer satisfaction in public service is an effective way to import market principles into the public sector, despite problematic effects on civic virtues, according to the author.
- The fourth order of problems relates to the potential for deception existent in the use of indicators. In fact, an incautious observation of reality through indicators can lead to deception about phenomena. C. Freeman (1995) provided two examples of how quantitative indicators could not explain changes in innovation systems. In a first example, the author showed that comparisons of R&D indicators were an

[28]Under the provisions of the Stability and Growth Pact, Members-states agreed to respect targets for two indicators: a deficit-to-GDP ratio of 3% and a debt-to-GDP ratio of 60%, in order to avoid excessive budgetary deficits. See http://ec.europa.eu/economy_finance/economic_governance/sgp/deficit/index_en.htm.

inadequate method to explain the Japanese institutional and technical changes of the 1970s and 1980s. In his opinion, these changes needed qualitative description because the Japanese quantitative performance erroneously identified a concentration in the fastest growing civil industries (e.g. electronics), with patent statistics showing their leading role at world level. However, these measures of research and inventiveness did not explain how these activities led to higher quality in new products and processes, to shorter lead times and to more rapid diffusion of technologies such as robotics. The second example came from the other side of the former iron curtain. According to Freeman, the former Soviet Union's commitment to greater R&D did not in itself guarantee successful innovation, diffusion and productivity gains, as the fall of the Berlin Wall would later show. In short, the use of indicators might lead to deception if only qualitative factors can describe the phenomenon.

- The fifth order of problems with indicators relates to the sensitive nature of their selection process. In fact, the selection of indicators can be a sensitive process for three main reasons: The selection of indicators can present significant methodological problems, which may arise from lack of data, the cost of information collection, superposition of indicators, reliability issues or time pressure, among others (Merry 2011; Gault 2013). Furthermore, the selection of indicators can produce constitutive effects in the future, as mentioned previously. In fact, the use of indicators can structure organizational activities; prescribe values and interpretations of reality embedded in indicators; create new meanings for words and vocabulary; project incentives, sanctions, norms and regulations, etc (Dahler-Larsen 2013). Third and last, the selection process can entail activities that are not trivial, conscious nor neutral, creating an implicit and sometimes controversial space for "politics", particularly if stakeholders use a different selection of indicators (this can be notably difficult in technology assessment studies - see next section). The criteria used to select indicators may be based on several factors, such as indicators' policy relevance, utility, analytical soundness and measurability (OECD 2003), as well as on other (sub)conscious factors allowing space for "politics". Therefore, there is the need for a clear formulation of the initial problem, which will enable a transparent selection of indicators that describe the problem to avoid controversies with stakeholders. Furthermore, the selection of indicators should also include space to reflect about the inclusion and the non-inclusion of certain indicators. For example, the use of composite indicators[29] for impressionistic propaganda (and oversimplification) by policymakers is an example of how indicators can be used (or rejected/downplayed) to suit political intent. The relevance of composite indicators to policy is perhaps best captured by the idea of indicators that become "policy-resonant" (Hezri and Dovers 2006, 87). According to the authors, an indicator that "strikes a chord" with its intended audience is easier to communicate, and often appropriated by policymakers and by the media (92). Sometimes, policymakers can claim that some indicators are difficult to interpret, and peripheral to the issues that generate political concern (Munda and Nardo 2005). However, the claim can also be interpreted as an example of how evidence is rejected because it does not suit a policy argument. In short, the selection

[29] The aggregation of indicators creates a composite indicator or an index.

of indicators is an important and sensitive process, and even sometimes a hazardous procedure that needs careful consideration.

The literature also revealed problems specific to innovation indicators, relevant in the context of technology innovation[30]. First, innovation indicators can present dangers to society through their increased complexity, ambivalence of interpretation, or decontextualisation; may present problems of confidence, comparability and overlaps; and may lead to "shaming and blaming" of countries and to media oversimplification (Feller-Länzlinger et al. 2010; Grupp and Schubert 2010; Nardo et al. 2008; Grupp and Mogee 2004). Second, there are limits to the use of indicators as an evaluation method of impacts of research and innovation funding and policies. In fact, Kuhlmann (2003, 137-9) warned against using indicators alone to perform these evaluations, because they are not compatible with the tendency to pursue complex political goals. In fact, the evaluations should combine various social science methods with indicators, according to the author. Third and last, there are problems associated with the aggregation of indicators in composites or indexes. In STI, there is an academic discussion about the purpose and methodologies used to gather data and build these types of indicators (Godin 2008; Nardo et al. 2008; Grupp and Mogee 2004; Barré 2004). Grupp and Schubert (2010) argued that some composite indicators in innovation were not subject to extensive research and may present confidence, comparability and overlapping problems. Nevertheless, scoreboards or composite indicators are often preferred by policymakers, as they can function as strategic instruments to influence policy change and communicate. In essence, the literature identified several problems related to innovation indicators and composite innovation indicators that should be taken into account in decision-making processes.

2.1.4 The role of indicators

The influence of indicators in general decision-making is largely unknown. Most literature aims to develop indicators, to analyse them or to evaluate them. However, only a few authors provided clues regarding the extent to which they are used to make a decision. These qualitative studies were mostly restricted to policy-making. In 1985, Duncan MacRae argued that the most frequent problem of indicators was their non-use in policy-making. The reasons for this disregard of indicators could be found in the lack of interest, or communication, information overload, or even opposition to what is being measured. A significant part of the existing literature about the influence of indicators in policy-making is, however, recent and resulted from two European projects: POINT - Policy Influence of Indicators and PASTILLE - Promoting Action for Sustainability through Indicators at the Local Level in Europe (Bell and Morse 2013). The existing studies in policy contexts revealed that most indicators were often ignored or that their use was limited in policy decisions (MacRae 1985; Lehtonen 2013; Sébastien and Bauler 2013). Sébastien and Bauler (2013, 3) emphasized that policy indicators remain largely enigmatic regarding patterns of embeddedness in institutional decision-making processes. In

[30] The concept of innovation and technology innovation will be developed in subchapter 2.2.

sum, literature about the extent of the use of indicators is meagre and mostly concentrated in policy-making. There is also some evidence that policy indicators were largely ignored.

Literature in innovation contexts is scarcer than in general policy-making. The two existing studies were published only recently and are centred in sustainable policy. In two case studies of sustainable transport policy at the national and EU-level, Gudmundsson and Sørensen (2012) found that indicators played a significantly limited direct instrumental role. The authors revealed that the use of indicators does not automatically mean influence on this type of policy or process. In fact, indicators may be used but are not really influential in the decision. Furthermore, in a second study about the significance of composite indicators for sustainable policy at the EU institutions, Sébastien and Bauler (2013) were convinced that composites were not systematically used directly, but had an indirect influence on policy-making that needs to be better understood. Most importantly, their conclusion emphasized the need to study the process of construction of evidence, rather than the technical quality of indicators and their independence from their producers (two factors initially presumed important). This latter work, however, dealt only with policy use of composite indicators by EU institutions. As mentioned previously, composite indicators can be controversial and present methodological problems. In fact, some authors considered composite indicators more adequate for policy communication and serving a competition function (Grupp and Schubert 2010). The latter authors pointed to the need for combining composites with information from other indicators to understand what to do in innovation policy. Hence, the existing literature about the use of indicators in innovation decisions is scarce and concentrated in two studies about sustainable policy. The limitations of these studies point to a need to understand the use of all types of indicators in innovation decisions.

The scarcity of literature about the role indicators play in innovation decisions is problematic. In fact, understanding the role of indicators in innovation decisions is important along three different lines. First, because the existing knowledge about the influence of indicators is based on only two case studies specifically about sustainable policy, it is difficult or even impossible to generalize about other topics of innovation. Critically, a broader understanding is needed because sector conditions might change significantly. For example, in a mature topic such as pharmaceutical policy there is a significant amount of accessible data, the political context is known and the stakeholders and policy impact are relatively easy to identify. By contrast, in an emerging technology field such as nanotechnology there is less information available, the field has a different political context and it can involve unspecified stakeholders or consequences. Second, innovation policies have implications for other actors of innovation.[31] These policies are intended to act upon the innovation system, changing the environment in which private and public researchers develop their innovations. The impact of innovation policies is also important for socio-economic growth and development in society. In fact, these policy decisions act upon the socio-economic system, where innovations can interact and

[31] As mentioned previously, these concepts will be developed in subchapter 2.2.

promote economic growth.[32] Hence, there is the need to understand how these decisions are made because they impact other actors and society. Last, the role of indicators in innovation decisions is important in understanding how these decisions are made and how actors behave. In fact, literature should identify the ways indicators are included in innovation decisions to enable an understanding of the behaviour of different decision makers in these processes. In sum, there is a need for further knowledge in innovation studies in order to make a discerned use of indicators and to improve actions in the innovation system.

The gap in the literature is also problematic for technology assessment (TA) studies. In fact, understanding the role of indicators is important to TA for six main reasons:

- The reflection about indicators is central to TA practitioners because problem-oriented studies frequently rely on indicators to address relevant societal questions about technology (Barré 2001). For example, in a TA study about the potential and the impacts of cloud computing services, Leimbach et al. (2014) used indicators of the type of use in cloud computing services and the type of cloud services to understand and explain the adoption and usage patterns of companies and consumers. Furthermore, while using a specific indicator the attention is focused on a selected aspect of the problem and ignores others. This raises the question on whether the existing indicators are contradictory or not, what can be known about a problem at stake while combing all the existing indicators and what are the limits of this knowledge. Thus, there is the need to reflect about indicators because they are often a main conceptual tool for analysing technological problems.
- Indicators cannot be seen as normative neutral instruments to analyse problems. In fact, although indicators are tools for describing and analysing a problem methodically, their selection is driven by criteria used by the actors proposing a focused description of a problem. These criteria evaluate indicators against the background of main cultural values or interests. For example, it is significantly different to observe an indicator of a CO_2 footprint of a product than to analyse the whole chain of different risk factors associated with the use of a technology. Furthermore, a TA position strongly oriented towards the precautionary principle[33] will also be expressed in the utilization of hazard indicators, because these address possible harm (with indicators of persistency or bioaccumulation potential) and not only concrete damage (with indicators of toxicity or carcinogenicity) (Böschen 2014, 42). Therefore, the selection of indicators is not normative neutral and is driven by specific criteria used by the actors proposing a focused description of a problem.

[32] As mentioned previously, these concepts will be developed in subchapter 2.2.
[33] The precautionary principle considers that we should not allow scientific uncertainty to prevent us from taking precautionary measures in response to potential threats, which can be irreversible and potentially disastrous (Resnik 2003).

- The description of complex TA problems and the strategies for their solution are heavily influenced by the use of indicators. For example, the use of an indicator of “security of livelihood” in a sustainability problem introduces a specific description of a selected problem, which is in this way placed as a key problem, influencing the definition of strategies for its solution. In another example, the use of the indicator of toxicity as a central problem of the regulation of chemicals introduces both a specific description of the problem and a strategy to deal with it (Böschen 2014). In many cases, the description through indicators and the classification of safety or precautionary strategies are interlinked.
- The selection of indicators needs to be as transparent and thoughtful as possible. In fact, the selection may not only lead to open new alternative technology options, but also may trigger significant controversies between TA practitioners and stakeholders that are used to a limited set of indicators. In fact, the group of stakeholders may be accustomed to frame the problem using indicators according to their cultural norms and/or their economic-political interests. For example, the debate about risks of nuclear power plants shifted in the moment the indicator of climate neutrality came in, because nuclear fission previously seemed to be a “green technology”. In this context, the selection of a “new” indicator can trigger controversy, because those involved with nuclear interests may tend to dismiss an indicator of climate neutrality. Thus, the selection procedure of indicators needs transparency and reflection to both open policy alternatives and reduce room for unnecessary controversies.
- The selection of indicators in TA requires substantial consideration because conditions for selection may change significantly in different fields of work. As mentioned before, in a mature field (e.g. pharmaceutics) there is accessible data, a known political context and identifiable stakeholders and policy impacts; however, in an emerging technology field (e.g. nanotechnology, synthetic biology) there is less information available, a different and evolving political context and unspecified stakeholders or consequences (cf. Torgersen 2009). Moreover, the use of indicators in mature fields needs continuous reflection as there might be changes in methodology or new empirical test settings relevant for uncover possible harm or damage (Böschen 2014). Therefore, the applicability of indicators in established fields needs reflection while transferring them to a new or different technology, as conditions can change significantly and/or there might be changes in methodology or new relevant empirical test settings.
- Last, an understanding of how indicators are involved in policy-making can help TA practitioners to better adapt their analysis to the specific need of the policy processes. In fact, insights about the policy process can help to differentiate from scientific and business processes, to develop public participation practices and to improve scientific communication of findings. In the policy process indicators are the cornerstones of the problem description and the solution process, and consequently of the problem which will be addressed politically and the strategies to solve it. Hence, it is decisive to make transparent and explicitly consider choices and the opt-outs of

indicators. Furthermore, the insights resulting from the understanding of the policy process can help identifying stakeholders and their interests, which is an important step to produce factual and neutral TA studies.

In addition, such a critical reflection is even more significant as TA in a policy analysis perspective has its own limitations. In fact, there are several constrains on the use of TA in policy-making, mostly related to the resources needed to facilitate the interaction between TA researchers and policymakers, as well as time restriction on the collection, consolidation, and dissemination of results (Reber 2006). The scientific staff of a TA organization often lacks experience of policy culture, although some lead double career paths and are trained both in the hard sciences and in policy-making, according to the author. Additionally, scientific analysis and political action are also based on significantly different logics. Scientific knowledge is likely to be strategically used (or ignored) opportunistically in the negotiation of different policy-making interests (Reber 2006). Policy processes also face significant demands for justification, especially in the media, insisting on reasons after or before political actions, according to the author. Therefore, it is important to link these two different spheres of action. TA, and in particular Parliamentary TA, has the comparative advantage of demanding deeper justifications for policies options and providing a structure where normative and scientific issues are granted a clearer voice (Reber 2006).

Nevertheless, for displaying this advantage a transparent system for structuring knowledge is needed. This is why a clear distinction has to be drawn between the general problem descriptions (which are offered by indicators) and their empirical foundation as well as their normative consequences. Böschen (2014) proposed to use a model build on three categories: indicators, criteria and observables. These three qualifiers of knowledge allow for reflecting on the construction and use of indicators. They can be defined as follows: Criteria evaluate indicators against the background of main cultural values or interests, and can be related to the indicators' policy relevance, utility, analytical soundness and measurability, and other (sub)conscious factors. Indicators are representing an effect-related aspect of a problem, which should be considered or solved. And finally, observables concretize indicators by providing specified methods for empirical observations or test strategies. This scheme allows clarifying to which layers the different arguments or empirical evidence are related to. Therefore, the model enables the classification of any sort of knowledge with respect to the description of a problem. Moreover, it offers an insight into the values seen as relevant for constructing the respective problem horizon.

In sum, the gap in the literature of the use of indicators in TA needs to be addressed because indicators are central to TA practitioners, are not neutral and can frame problems and strategies to solve them, the selection of indicators needs to be transparent and thoughtful to open alternatives and avoid unnecessary controversies, and the insights about the policy process can help in the development of TA studies. A structure of criteria, indicators and observables can be used to clarify the choices in TA studies.

In this context, there is a need to conduct research about the role of indicators. An understanding of the influence of indicators in both innovation and in TA studies implies a special focus on technology innovation[34]. In fact, this focus extends the analysis to other areas of innovation and to other innovation actors (e.g. researchers and business R&D&I leaders)[35] not previously covered by the literature, maintaining a focus on TA. Therefore, the analysis will first concentrate on disentangling the use of indicators from their factual relevance in decision-making[36], because separately they allow an understanding of their real importance in the decision process. Research will need to provide information about the extent of use and influence of indicators in the decision process of technology innovation by each innovation group[37]. Thus, the first research question can be expressed as follows: (*Q1) Is the use of indicators different from their influence in decisions of technology innovation made by the three innovation groups?* The literature reviewed previously suggests the formulation of the following hypothesis: (*H1) Despite their high level of use, indicators have low influence in decisions of technology innovation made by the three innovation groups*. The hypothesis contains several concepts already introduced (e.g. indicators, use of indicators and influence of indicators), and others that will be developed in subchapter 2.2 (e.g. decision-making, technology innovation and innovation groups).

The literature reviewed also points to the need to determine the role that indicators play in those decisions made by each innovation group. The literature provided partial qualitative results. Thus, it is important to determine a quantitative background about the role of indicators in technology innovation. In this context, the second research question can be expressed as follows: (*Q2) What is the role of indicators in decisions of technology innovation by the three innovation groups?* The literature points to the following formulation of the hypothesis: *(H2) Indicators have a symbolic role in decisions of technology innovation made by the three innovation groups.* This hypothesis contains several concepts already introduced (e.g. indicators, use of indicators and influence of indicators), and others that will be developed in subchapter 2.2 (e.g. decision-making, technology innovation and innovation groups).

However, there is another concept related to the role of indicators where the literature can provide immediate guidance. In fact, the role of indicators in policy contexts was categorized by Gudmundsson and Sørensen (2012) into four groups: instrumental, conceptual, process and symbolic. The authors first state that the instrumental role of an indicator is its direct influence and direct use as a tool in forming a decision. Second, an indicator's conceptual role is its contribution to shaping knowledge or introducing new ideas, while being neither immediately used nor influential in decisions. Third, the process role: an indicator used over time affects the way some aspect of policy-making is conducted, regardless of what the indicator reveals directly. Fourth and last, its symbolic

[34] The concept of technology innovation will be developed in subchapter 2.2.
[35] The concept of innovation actors will be developed in subchapter 2.2.
[36] The concept of decision-making will be developed in subchapter 2.2.
[37] The concept of innovation groups will be developed in subchapter 2.2.

role, as the indicator is used to justify decisions that have already been taken, or to give a rational appearance to the decisions. According to the authors, this latter role may still embody policy influence in terms of policy legitimacy or in terms of the balance of power.

Nevertheless, the conceptual and process roles present significant difficulties for technology innovation decisions, probably because they were formulated to analyse specific policy cases. There are four types of difficulties within these two categories: First, there is significant difficulty in distinguishing conceptual influence from process role, because an indicator that contributes to shaping knowledge or introducing new ideas (conceptual role) may also affect the way some aspects of how policy-making is conducted (process role). Furthermore, an indicator may be used over time (process role) while not used immediately or influentially in the decision (conceptual role). Second, a conceptual role may not exist in practice for a scientist, an engineer, a manager or a policymaker. In fact, when reflecting upon the role of an indicator in a technology decision, it is difficult to state that an indicator was not influential if a decision maker admits it contributes to shaping knowledge and introducing new ideas. To her/him an indicator that contributed to shape new knowledge and ideas inevitably produces changes in the framework of decision,[38] and consequently was influential in the decision. Third, it is difficult to admit that an indicator influenced some aspect of the decision regardless of what it directly demonstrates. Fourth and last, from a practical point of view, an indicator is an objective concept that is either present or not in a concrete technology decision. Indicators can hardly be a part of a decision, through shaping knowledge or introducing new ideas used over time, without being immediately used in a decision. Therefore, these distinctions between conceptual and process role are difficult to use in the analysis of the role of indicators in decisions of technology innovation.

Consequently, indicators can only be considered to have an instrumental role, a symbolic role or no role at all in decisions of technology innovation:

- An *instrumental role* means that indicators had direct influence and were used as a tool to make a decision. The instrumental role of indicators in a decision implies that a rational-analytical method[39] was used. In addition, this role also suggests that a rational-analytical approach was applied alone or combined with a political-behavioural and/or an emotional-intuitive approach (these concepts will be developed in the next subchapter).
- A *symbolic role* means that indicators were used to justify decisions after they have been taken, or to give a rational appearance to decisions. The symbolic influence implies that a rational-analytical method was not predominantly used to decide. This role shows that the predominant decision approach was political-behavioural or emotional-intuitive, either alone or in interaction with a rational-analytical method (see next subchapter).

[38] Through constitutive effects, for example.
[39] The concept of rational-analytical method will be presented in subchapter 2.2.

Some authors argued that quantification needs are mostly symbolic at policy-level, where they can have a relative influence (Gudmundsson and Sørensen 2012; Perri 6 2002). Perri 6 (2002) claimed that decision makers use a certain amount of knowledge when making a decision, and their judgments are dependent on where actors are socially situated and integrated. This view implies that the influence of indicators is determined by the social "cage" of users, where social relations act upon individuals constraining and guiding them both consciously and unconsciously in their decisions. Therefore, to understand the role of indicators, it is necessary to inquire about the influence of social relations in the decisions of different groups.

– Last, indicators had *no role* at all is a category that can be associated with situations where information does not exist, is incomplete or ambiguous. It can also be related to situations where the consequences of the decisions are significantly unpredictable, such as when high levels of uncertainty, disagreement or complexity exist (see next subchapter). The absence of indicators reveals a lack of rational-analytical tools in the decision process. These conditions have been associated with predominantly emotional-intuitive approaches, such as judgement or gut feeling, but can also include political-behavioural approaches (see next subchapter). Therefore, "no role at all" for indicators shows that an emotional-intuitive and/or political-behavioural approach existed, either alone or in interaction.

As discussed previously, the way indicators are involved in decision-making has been scarcely studied, despite its significance for innovation and TA studies. Thus, research will also focus on understanding the way indicators are involved in decisions of technology innovation. Hence, the third and last research question can be formulated as follows: (*Q3) How are indicators used in decisions of technology innovation?* There are four possible explanatory factors that can affect the way indicators are used in these decisions:

The first explanatory factor considers the *type of decision*[40] to be potentially helpful in describing the way indicators are used in decisions of technology innovation. Each type of decision contains different characteristics that determine the way indicators are used. For example, in an acquisition of equipment/technology it can be expected to involve indicators related to the financial context of the decision. Besides financial indicators, the acquisition might require indicators about technical characteristics of the product/technology, or related to human resources or suppliers needed to operate it. Other types of decisions might not be so dependent on financial indicators. A policy decision about technology regulations might not involve economic indicators and might be more based on technical indicators, work organization, market share or benchmarking. The availability of information (studies, opinions, sectoral information, etc.) can also be relevant in policy contexts. Furthermore, a decision to acquire a patent in a business or laboratory context might be based on technical indicators, qualification of human resources, the use of technology by competition or by partners, as well as other

[40] The concept of type of decision will be further expanded in subchapter 2.2.

types of financial indicators, such as accounting, IRR[41], VLA[42], or Payback. In addition, a company decision about development of product/technology can be based on judgement and considerations of colleagues and not involve indicators at all. Therefore, the type of decision may be important to explain the role indicators can have in decisions of technology innovation. Consequently, the following hypothesis can be formulated as: *(H3) The type of decision helps to explain how indicators are used in decisions of technology innovation.*

The second explanatory factor is that the *phase of the decision* process can help explain the way indicators are involved in decisions of technology innovation. There are four main reasons to suggest that the phase of the decision process is relevant in understanding the way indicators are used: First, decisions of technology innovation can require different considerations for indicators, not just before but also after the decision. For example, the decision to buy expensive equipment for a research laboratory may require previous intensive considerations about the cost, and no such deliberation afterwards. In other cases, however, indicators can also be used afterwards. This use is often related to the need to justify, monitor, control or evaluate the outcomes of the decision. For example, a decision to develop a new product in a company can cause intensive concerns after the decision, based on indicators of cost or weight; a leader of a research project might need to use indicators to justify expenditures to the European Commission; even policy-related indicators may be intensively used after the final decision in order to monitor, control or evaluate policy effects. Second, some decisions may include the use of indicators more or less intensively in different phases. For example, a decision to develop a new product in a company may not need an intensive use of indicators of cost and weight in the preparation phase. Afterwards, the decision may require an intensive use of these indicators to adjust the product for the future market. Third, Sébastien and Bauler (2013) found that composite indicators had the most relevance during early descriptive phases of a policy-making process (i.e. to identify gross policy problems). Fourth and last, Frederiksen and Gudmundsson (2013) suggested the existence of two or more phases where a conceptual role is prominent in the preparation phase, where indicators are conceived, selected and developed, while instrumental and strategic roles dominate policy implementation phases. Therefore, the phase of the decision process may explain the way indicators are used in decisions of technology innovation. Consequently, the following hypothesis can be formulated: *(H4) The phase of decision helps to explain how indicators are used in decisions of technology innovation.*

A third explanatory factor for the way indicators are used can be found in the *context*[43] of the decision. As it will be argued in subchapter 2.2, there are contextual factors that can influence the way a decision-making process occurs. In fact, an adversarial political context may influence the way indicators are included in the decision by stimulating the need for indicators to support arguments; a

[41] IRR is the acronym of Internal Return Rate.
[42] VLA is the acronym of Net Present Value.
[43] The concept of context will be further expanded in subchapter 2.2.

lack of economic resources may push for formal evidence to support a decision of technology innovation; and other organizational factors can influence the decision process (e.g. structure and qualifications). Consequentially, the following hypothesis can be formulated: *(H5) The context helps to explain how indicators are used in the decisions of technology innovation.*

A fourth explanatory factor for the role of indicators may be found in the *process of construction of evidence*, as suggested by Sébastien and Bauler (2013). There are two mains reasons for this: First, the selection or the disregard of an indicator can be a controversial choice, particularly in contested policy arenas. Furthermore, the "strategic and political use of indicators, manipulation or even abuse of indicators is not necessarily a problem, but rather an essential part of the production of valid and reliable evidence" (Sébastien and Bauler 2013, 10). For example, a significant increase in the number of patents in a country in a year can be introduced as evidence of governmental efforts to promote innovation. The example makes a controversial assertion[44] that governments can directly claim to promote innovation, despite the efforts of companies and research institutions. If this controversy is brought to the debate, the policy process will determine the influence of the indicator in providing rational-analytical support to an innovation policy decision. Second, in policy contexts, indicators are used to reduce ambiguity (Sébastien, Bauler, and Lehtonen 2014) and may be introduced to reduce the number of variables observed, to simplify and facilitate communication, and to build clear and unambiguous visions of the desired future (Sébastien and Bauler 2013). In these processes, indicators are expected to communicate evidence in a form suited for policy actors that simplify the description of complex systems (Sébastien and Bauler 2013). In these cases, the role of indicators will be dependent on their availability and capacity to play a role in the debate. Therefore, the present work will also focus on understanding the process of constructing evidence in decisions of technology innovation in order to explain the way indicators are used. Consequently, the following hypothesis can be formulated: *(H6) The process of construction of evidence helps to explain how indicators are used in decisions of technology innovation.*

Last but not the least, the main concepts that need to be articulated with these four hypotheses are introduced: type of decision, phase of decision, context of decision and process of construction of evidence. Furthermore, other concepts are already described, such as indicators and the role of indicators. In addition, the following subchapter will develop remaining concepts, such as technology innovation, decision-making, decision-making models of technology innovation and innovation groups.

[44] It can also be said to be a simplification of reality, because innovation efforts can be measured using evidence other than patents.

2.2 DECISIONS OF TECHNOLOGY INNOVATION

This subchapter introduces concepts needed in understanding the decision process of technology innovation. It will be argued that technology innovation can be understood as a phenomenon occurring in a process of innovation, where interactions occur between different actors. These interactions form a network of relationships between decision makers and other stakeholders, who can support policies to influence the innovation system. The subchapter is composed of three sections. The first section deals with technology innovation, defining the process of innovation, its actors, networks and innovation policy. Afterwards it presents a model to interpret decisions of technology innovation and identifies possible methods for making decisions. The third section discusses the types of decisions of technology innovation, and conditions of uncertainty and complexity affecting these decisions.

2.2.1 Technology innovation

An innovation is commonly defined as a new idea, device or method.[45] The result of an innovation is normally a technological product/service, or the significant improvement of a product or process. Innovation is distinct from an invention or technical prototype, and refers to a technology actually being used or applied for the first time (Utterback 1974). Most innovations occur embedded in innovation processes, where a set of inventions and implementation of new ideas are developed by individuals, who engage in transactions with others, over time, within an institutional context, judging outcomes of their efforts and acting accordingly (Van de Ven and Poole 1990).[46]

Furthermore, there are several types of innovations such as product, process, organizational and marketing. The present work will focus only on technological product or process innovations. These type of innovations comprise the implementation of new products and processes or significant technological improvements in products and processes (OECD, European Commission, and Eurostat 2005).[47] The present focus is based on the idea that technological innovation is important to society and firms. In fact, the new technological products and processes can induce technological change which, in turn, can promote growth and development in societies (Poole and Van de Ven 2004). These technology innovations can offer opportunities to firms to capture new markets, achieve high profits and build dominant positions in the marketplace (von der Gracht and Stillings 2013). These innovations also act upon organizations, being a route to revitalization through exploitation and exploration of competencies in the firms (Cheng, Chang, and Li 2013). In sum, technological product

[45] "Innovation" Oxford Dictionary Online. Last accessed in 21/12/2014. http://www.oxforddictionaries.com/definition/english/innovation.

[46] Innovation process should not be confused with process innovation. The former refers to the process of introducing new ideas, devices or methods. The latter is a formal classification of innovation targeting the process of production and/or delivery of goods and services.

[47] An innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation), and involves scientific, technological, organisational, financial and commercial activities (OECD, European Commision, and Eurostat 2005:31).

and process innovations are important to social and economic development, firms' opportunities and to the revitalization of organizations.

Technology innovation can however create problems that cause questioning of the relationship between the goals of technology and its unintended consequences. Thalidomide, Seveso, Bhopal, Chernobyl and Fukushima remain historical, world-renowned examples of the unintended effects of technology. In fact, these and other cases have been responsible for changing perceptions and stimulating the discussion about undesirable consequences of technology innovation since at least the 1950s. Reflection on this problem shows the extent to which science and technology have become risky and are being driven into more complex designs, "in a society which has no other way out but to accept risks" (Bechmann et al. 2007, 18). In Germany, for instance, the recognition of this problem led the government to institutionalize technology assessment activities to investigate scientific and technological developments, with a focus on their impacts and possible systemic and unintended effects.[48]

The context where technology innovations occur is frequently named the innovation system. This system encompasses all institutions engaged in research and the accumulation and diffusion of knowledge, educating and training the population, developing technology, producing innovative products and processes and distributing them (Kuhlmann, Shapira, and Smits 2010). Smits, Merkerk, and Guston (2010, 1) described this encompassing perspective:

> According to this [systemic] view, we can no longer see innovation as a given thing – as an invention. Instead, innovation is a systemic process involving a heterogeneous set of actors who are inspired by both the potential that science and technology offer and by the context in which they have to function. These actors are involved in a complex decision-making process that leads to innovative activity (Smits, Merkerk, and Guston 2010, 1).

Thus, the study of an innovation system is a heuristic attempt developed to analyse all subsystems in society, actors and institutions that contribute, directly or indirectly, intentionally or not, to the emergence of innovation (Hekkert et al. 2007). Furthermore, this broad conception of the boundaries of innovation in society is based on the idea that institutions can affect the development of innovations. In fact, institutions can influence[49] the pace and direction of innovation, with time delays in the decision-making process or with lock-in effects to prevent technological developments (Stirling 2007; Samara, Georgiadis, and Bakouros 2012). This institutional view, however, is not so dominant in the US as it is in Europe (Kuhlmann, Shapira, and Smits 2010). In fact, to some critics this conceptualization implies institutional determinism, disregards the power of the entrepreneur to act in

[48] An example of this institutionalized activity is the Institute for Technology Assessment and Systems Analysis of the Karlsruhe Institute of Technology, founded in 1995 as successor of different institutions with similar roles in Germany since 1950s (Wingert 2005).
[49] According to Knoke (1993), influence occurs when one actor provides information to another with the intention of altering the latter's actions. Influence is a relational dimension of power, because a two-way communication channel must exist between an action and its consequences (Knoke 1993).

the system, and might lead to a static approach of a dynamic system (Hekkert et al. 2007). Nevertheless, bearing these criticism in mind, the innovation system approach remains one of the most referred concepts in literature for understanding and reflecting upon innovation (Fagerberg, Fosaas, and Sapprasert 2012).

2.2.2 Innovation actors

Most individuals involved in innovation activities can be classified into three different groups[50]. First, innovation processes often occur within a business context. Here, privately hired scientists and engineers are usually involved in innovation, working either in R&D contexts or in specialized innovation departments. Second, innovation also occurs in the context of R&D projects developed by groups working in the public sector, namely scientists, engineers, academics and medical doctors. Third, technology innovations also depend on the decisions of policymakers, who make decisions that normally play a significant role within the innovation system by defining the context where innovations occur. Their decisions are directly related to innovation policies, which can produce (or constrain) significant technological developments. For example, Stirling (2010, 1031) argued that a "locking-in" effect can occur when a government prioritizes certain areas of scientific enquiry over others. Furthermore, the interactions between policymakers and other groups of innovation actors have been identified in the literature. For example, Kuhlmann, Shapira, and Smits (2010) pointed out that innovators have not only asked for and received public financial support, but also pushed for changes in regulation, in order to facilitate the adoption of their solutions and to exploit state-guaranteed intellectual property rights. In addition, there are other individuals or entities that can play a role in the innovation system, although their role tends to be more indirect. For example, venture capitalists, banks or activists can promote or constrain innovations through their indirect actions in the system or, more generally, in society. Nevertheless, their influence in technology innovation is mostly indirect and significantly influenced by interactions with the three groups.

Consequently, the main units of analysis for this research are the three main groups of an innovation system: (1) The group composed of public researchers, academics, and R&D health personnel, hereafter named *researchers*; (2) Business Research, Development and Innovation (R&D&I) leaders: a group composed by team leaders of R&D&I departments in companies, hereafter named *business*; and (3) Policymakers related to technology innovation: a group broadly involved in technology decisions from a policy perspective, such as the design of strategies to address the innovation system. It should be noted that the main difference between public researchers and business R&D&I leaders is the goal to financially profit from their decisions in technology innovation. This different emphasis is important for understanding the role of indicators in the decisions. Furthermore, there are both common and individual reasons to target these three groups. The main reason for this

[50] In this context a group consists of a finite set of actors who for conceptual, theoretical or empirical reasons are treated as a finite set of individuals on which network measurements are made (Wasserman and Faust 1994).

selection is that the groups were composed by individuals who reported technology decisions recently; have access to and use vast amounts of techno-scientific knowledge; normally have contact with indicators; and possess skills to deal with indicators. These groups are also closely linked with the innovation system and play important roles in its functioning. In addition, there are individual reasons to focus on these innovation groups:

1. Researchers were selected because they influence technology developments in at least four different ways. First, they are involved in R&D projects that can lead to new technologies and innovations. Second, the group is partially involved with students before they reach decisive positions, where they will influence other communities in technology options. Third, these individuals are frequently called to decide upon significant investments that directly or indirectly influence technology choices (e.g. research programs and projects; setting up new laboratories, universities, hospitals, clinics and other specialized institutes; and acquiring powerful microscopes, jet printers and diagnosis machines). Fourth and last, this group informs and helps decision makers with technology options. For example, they assist in important public and private choices, such as the development of satellites, transport systems, and other research-related facilities; acquisition of submarines, supercomputers, helicopters and airplanes; the construction of highways, bridges and dams, etc.

2. Business R&D&I leaders were selected because they are most frequently found leading innovation departments of firms or in charge of R&D projects. They are responsible for most choices regarding the development of new products or new technologies, and are frequently in charge of important strategic decisions in innovative companies.

3. Policymakers were selected because they are involved in technology decisions, such as the design of policies that address the innovation system. These policies can involve programs, projects, ideas, legislation and other regulatory frameworks that directly or indirectly affect the development of technology innovations. For example, the policymakers deal with policies and legislation designed to promote Science & Technology (S&T) graduates, support patenting efforts, backing high-tech companies, financing R&D projects, etc.

In sum, these three innovation groups are involved in decisions that shape and influence present and future technology innovation developments and socio-technological pathways.

However, the research will not target other individuals or groups that can interact with an innovation system. In fact, some inventors working alone were not included in the research because some only have a one-time relationship with the innovation system. For example, some inventors were not inventors before the invention or are not long-term inventors. Second, inventors are significantly difficult to approach in a survey because they are not cohesive enough to be called a group of actors.[51]

[51] Generally, social groups are a collection of individuals who interact and form social relationships (Abercrombie, Hill, and Turner 1984). Some of these inventors do not interact with one another significantly

Furthermore, other actors, such as business angels and financial investors, are not normally directly involved in making technology decisions. In fact, they often make investment-related decisions within their frameworks of business opportunities, leaving technology innovation decisions to business R&D&I leaders or researchers. In addition, the non-governmental organizations, lobbies, networks and other groups that exist in an innovation system do not make technology decisions directly, although they can influence the success/failure of a technology.

The innovation process can be influenced by individuals, firms and society in different ways. Companies can be influenced by the culture where the organization is embedded and by individuals who act upon firms. Nation states are the origin of most firms, which tend to develop and evolve in compatible ways with the surrounding national culture (Černe, Jaklič, and Škerlavaj 2013). According to Černe, Jaklič, and Škerlavaj, national culture is manifested in the collective beliefs and shared values by individuals within a certain national environment. Naturally, the national culture affects and interplays with corporate culture, and has been directly related with various aspects of innovation, in particular investments in innovation (Hogan and Coote 2013; Černe, Jaklič, and Škerlavaj 2013). To conclude, the innovation process can be influenced by entrepreneurs, employees, organizational contexts and cultural values of the society that embedded them.

An innovation process influences other actors in the innovation system. In fact, the actors of an innovation process influence other actors, directly or indirectly, through the behaviour of the innovator and the effects produced by the innovation itself in the system. These relationships of influence among actors constitute a network of innovation.[52] A network assumes that actors affect each other through interactions that enable them come to hold similar views and/or become aware of similar bits of information (Borgatti, Martin, and Johnson 2013).[53] These networks can capture innovation efforts both in an action and across time. Hence, the collective and individual efforts in an innovation policy can be depicted as a network that captures all interactions and efforts leading individuals to act and hold similar views and/or become aware of the same information.

Network theory presents a valuable relational view of social phenomena, based on the structure of the network and the position of actors. In theory, the actor's position determines in part the constraints and opportunities that an actor will encounter, and can help to predict the actor's outcomes, such as performance, behaviour or beliefs (Borgatti, Martin, and Johnson 2013). At the group level, what

enough to form these relationships. Furthermore, a group can be defined narrowly as "a number of individuals, defined by informal or formal criteria of membership, who (a) have some shared sense of identity or (b) are bound by relatively stable patterns of social interaction" (Bruce & Yearley, 2006, 128). In this case also, some of these inventors do not share a sense of identity and are not bound by relatively stable patterns of social interaction to be considered as a group.

[52] Networks are a way of interpreting social systems that focus attention on the relationships among the entities (i.e. actors) that make up the system (Borgatti, Martin, and Johnson 2013).

[53] These innovation networks are organizational forms which serve for information, knowledge and resources exchange and which help to implement innovation by mutual learning between network partners (Koschatzky 2001). The advantage of networks lies in the acquisition of complementary resources, which an individual actors does not have at his own disposal, according to the author.

happens to a group of actors is in part a function of the structure of the connections among them, according to the authors. A social network, therefore, consists of a finite set or sets of actors and the relationship or relationships defined by them (Wasserman and Faust 1994; Marin and Wellman 2011). Consequently, social network analysis is a systematic framework to retrieve meaningful information from a given social network (Park 2011).[54] Furthermore, the network structure is shaped by actors to specifically achieve their own outcomes. It is not an actor's intentions and actions taken in order to occupy a certain position that creates the outcome, but the actual occupation of the position (Borgatti and Halgin 2011). In fact, occupying a specific structural position carries certain potentialities, but the actual outcomes may depend on a number of additional factors, including how the actors play their role. Therefore, network theory can help in understanding the network structure and the outcomes in a decision.

A social network is composed of a set of socially relevant nodes connected by one or more relations (Marin and Wellman 2011). The study of these networks allows us to "map" the interactions between the decision makers of the networks used to make a decision. This type of analysis also provides empirical metrics for the networks developed to make decisions. For example, the measures of the whole network (e.g. centralization, density and connectedness) allow a critical view of how a network is structured and how it works. Other measures can also be useful to interpret a network, with metrics about the centrality and core-periphery of actors in relation to the network, and the existence of factions within the network. Overall, social network analysis reveals insights on how decision makers organize themselves to conduct a decision process about technology innovation.

Some measures have been proposed to analyse the characteristics of social networks. In fact, the two main characteristics of networks are their cohesion and shape (Borgatti, Martin, and Johnson 2013). Cohesion measures describe characteristics of cohesion among actors. The shape of the network allows the examination of its centrality, as well as the detection of the existence of sub-structures within the network, such as a core and periphery and the existence of factions. An important dimension of position in the network can be captured through centrality, both at the network and individual/node level. Conceptually, centrality identifies which nodes are at the "centre" of the network. Centrality measures are a family of node-level properties relating to the structural importance or prominence of a node in the network (Borgatti et al. 2009). However, identifying the meaning of "centre" in practice is complicated. The simplest notion of centrality focuses on degree of centrality: the actor with most ties[55] is the most important. Unfortunately, the degree of centrality can be deceiving, because it is a localized measure failing to account for the whole network (Borgatti, Martin, and Johnson 2013). There are many ways to construct such measures, but one that has become

[54] Social network analysis may also be viewed as a broadening or generalization of standard data analytic techniques and applied statistics which usually focus on observational units and their characteristics (Wasserman and Faust 1994).
[55] The network ties serves as a bond that aligns and coordinates action, enabling groups of nodes to act as a single node, often with greater capabilities (Borgatti and Halgin 2011).

standard is the Freeman's general formula for centralization that takes into account the whole network (Wasserman and Faust 1994; L. C. Freeman 1979).[56] Another measure of centrality is closeness centrality, where an actor is considered important if he/she is relatively close to all other actors. Closeness is based on the inverse of the distance of each actor to every other actor in the network.[57] A third measure of centrality is the Eigenvector centrality (Bonacich 1987; Bonacich 2007), where the actor's centrality or prestige is equal to a function of the prestige of those he/she is connected to. In this case, actors who are tied to very central actors have higher centrality prestige than those who are not. The Eigenvector centrality is a measure of popularity in the sense that a node with high Eigenvector centrality is connected to nodes that are themselves well connected (Borgatti, Martin, and Johnson 2013).[58] In sum, there are two main characteristics of networks - cohesion and shape - that help to understand the network and the actors' outcomes. The shape allows the determination of centralities (Freeman's, closeness and Eingenvector), as well as the cores and factions of the networks.

There are networks specifically organized to make policy decisions (Rhodes 1990). Like in any social network, a policy network consists of a bounded set of actors and one or more sets of relations that connect these actors (Knoke 2011). The difference in these networks is that the ties represent interactions created to provide advice and to help those involved in the decision process (Borgatti et al. 2009). These policy networks can help in understanding the processes of decision-making through characterizing and comparing decision networks. Some authors have shown that policy networks help identify the influence each actor has on another, detect the most salient actors involved in decision-making, and determine influences in the use of evidence (Christopoulos and Ingold 2014; Fischer 2011; Drew et al. 2011; Knoke 1993). Therefore, the analysis of policy networks can help understand how decision networks and individual actors are formed and behave.

There is another theory related to networks of innovation that should be mentioned: the actor-network theory. In fact, the theory considers that actors include not only living persons but also non-living technological entities (Winner 1993). An example used to introduce "things" in a network was electric vehicles. In fact, the introduction of electric vehicles in France in the early 1970s helped in explaining the interplay between technology and its actors (Callon 1989 and 2012). Michel Callon (2012) argued that actors form networks of action that arise in everyday life, and should not be reduced to purely social relations. To the author, these networks need to include "things" or

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[56] Freeman's general formula for centralization is $C_D = \frac{\sum_{i=1}^{g}\left[C_D(n^*) - C_D(n_i)\right]}{[(g-1)(g-2)]}$. For more details, please see Wasserman and Faust (1994, 180).

[57] The formula for closeness centrality is $C_c(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j)\right]^{-1}$. For more details, please see Wasserman and Faust (1994, 184).

[58] The formula for Eigenvector centrality is $e_i = \lambda \sum_j x_{ij} e_j$. For more details, please see Borgatti, Martin, and Johnson (2013, 168).

heterogeneous elements, animate and inanimate, such as engineers, contaminated catalysts and fuel cells. They have all been linked to one another for a certain period of time, and "things" function as intermediaries between humans (Callon 2012). However, the concept - advanced by Callon (1989 and 2012) and other authors such as Bruno Latour and John Law (Callon and Law 1989) - was significantly criticized because the authors insisted on the contradicting capacity of nonhumans to be actors (Winner 1993). Furthermore, actor-network theory remains difficult to apply, particularly in terms of boundaries of the system and the complexity involved. In addition, the analysis of decision-making in a policy network usually occurs without non-living technological entities, and it requires a defined boundary of relationships of influence. Therefore, actor-network theory is not significantly useful for understanding policy networks, which by definition involve policymakers and lack nonhuman entities.

A policy network is created to design an innovation policy. The term *policy* generally signifies an intentional course of action followed by a government institution or officials for resolving an issue of public concern (Cochran et al. 2009). In this interpretation as a public action, policy requires laws, public statements, official regulations, and/or widely accepted and publicly visible patterns of behaviour. Furthermore, some policy actions are intended to influence the innovation system. These policies can thus be defined as a set of policy actions to increase or improve the quantity and efficiency of innovative activities[59] (Cowan and van de Paal 2000). The rationale for these policies is that innovation generates more economic growth, which in turn promotes higher levels of employment and job creation (Colombelli, Haned, and Le Bas 2013). In addition, the notion that new knowledge leads to innovation, and therefore more growth and knowledge, is a commonly accepted rationale for implementing innovation policies in both Europe and America (Colombelli, Haned, and Le Bas 2013).

A process of innovation can be significantly complex, slow and difficult to influence. However, policymakers can act as enabling actors and catalysts:

> The challenge of governments is not to maximize some imaginary welfare function, but to ensure that the processes of co-evolution of technological supply and demand lead to desirable outcomes, in both the short term and the long run. (Kemp et al. 1998, 191)

There is no guarantee of success in these actions because changing circumstances may render the technology less attractive and technological promises may never materialize (Kemp et al. 1998). Furthermore, the active involvement of stakeholders is crucial to success (Chan 2013). In fact, governmental action is not per se sufficient to promote technology change, particularly when the problem requires the integration of different actors. In addition, there are two other mechanisms limiting the dynamics of policy interventions in innovation systems (Hoppmann, Huenteler, and Girod 2014). One mechanism relates to the role of politics and interest, where politicians anchored in an

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[59] By innovative activities, the latter authors meant the creation, adaptation and adoption of new or improved products, processes or services.

existing socio-technical regime are unlikely to support emerging technologies that cannot yet provide them with a constituency. These policymakers may also hold different opinions on system failures and how to remove them. Another mechanism likely to constrain the dynamics of policy intervention is the limited capacity and foresight of policymakers. In this case, Hoppmann (2013) stressed that, even when there is political consensus regarding goals and means, the inherent complexity of socio-technical systems may limit or hinder the degree to which consequences of policy interventions can be foreseen. In fact, the focus of policy interventions requires a careful analysis of the socio-technical system to identify system failures or bottlenecks that could be difficult to enact. Policymakers generally have a limited capacity to obtain and evaluate all possible policy measures and outcomes (Kemp et al. 1998). Consequently, they tend to design policies based on learning from past experiences. The problem with learning from past policy experiences is that innovation systems evolve in a non-linear and often unpredictable way, which can create unexpected effects.

2.2.3 Decision process

Decision-making is a general term applied to the process of making a choice between options, through which individuals arrive at a decision (Nitta 2013). Mintzberg and Westley (2005, 75) described it as the process of gaining an insight, in the sense of “seeing into”, which suggests that decisions, or at least actions, may be driven as much by what is “seen” as by what is thought. Furthermore, on a general level, the decision-making process can be described as based on three different activities (Andersson, Grönlund, and Åström 2012; Simon 1979): intelligence activity, where the need for a decision is identified; design activity, which starts when the need for a decision is identified and the problem is investigated by developing the domain to find possible alternatives; and last, the choice emerges when a decision is ready to be made through the selecting of the most appropriate course of action from the alternatives previously found. The process is complex and can include returning to the intelligence phase, or include the same cycles inside one single phase.

There are many models of decision-making. Decision-making models are conceptual frameworks for understanding how decision makers deal with information and arrived at conclusions (Harren 1979). They are simplified descriptions of a psychological process in which a decision maker organizes information, deliberates alternatives and makes a commitment to a course of action (Harren 1979). Decision-making is a multidisciplinary topic that has received significant contributions from various disciplines and fields of science. For example, concerns about the bounds of rationality of economic agents came from economics; efforts to understand impacts of decisions in firms came from management science; impacts and implications of decisions for political action came from political science; and concerns about internal decision mechanisms of individuals came from psychology. It is therefore not surprising that most explanations about decision-making are bounded to the disciplines and fields of research of the authors, such as economics (Simon 1959; Simon 1979; Menzel 2013; Kahneman 2011), business (Jauch and Glueck 1988; Swami 2013; Schoemaker and Russo 1993; Sull and Eisenhardt 2012), and psychology (Curseu and Schruijer 2012; Schwartz et al. 2002; Starcke and Brand 2012), as well as health (Smith, Higgs, and Ellis 2008; Murray et al. 2007), education (Galotti et al. 2006; Harren 1979) and military studies (Thunholm 2004; Scott and Bruce 1995).

The literature does not provide a model for understanding decisions of technology innovation. There are various decision models, which can include an extensive variety of dimensions for decision-making (see among others Scott and Bruce 1995; Hunt et al. 1989; Harren 1979; Swami 2013). For example, in an organizational study of decision-making models with senior managers, Turpin and Marais (2004) described nine existing approaches to decision-making: rational, bounded rationality, incrementalist view, organizational procedures view, political view, garbage can model, individual differences perspective, naturalistic decision-making and multiple perspective approach. Other studies were less abundant in the number of possible ways to make a decision. For example, in a military-oriented study, Peter Thunholm (2004) described five ways to make a decision (independent and not mutually exclusive): rational, intuitive, dependent, avoidant and spontaneous.[60] However, although the rational and emotional-intuitive approaches were unproblematic from a theoretical point of view, the intellectual foundations of the other were unclear (Thunholm 2004). The author admitted, for instance, that his spontaneous decisions "might perhaps be viewed as a kind of high-speed intuitive decision-making style" (Thunholm 2004, 934). Nevertheless, the literature reveals that most models of decision-making propose a rational-analytical and an emotional-intuitive approach, to explain the major considerations dominating the attention of an individual during the decision. Therefore, given the variety of approaches that can be considered in a decision model, there is a strong case for using a rational-analytical and an emotional-intuitive approach in a technology innovation decision model.

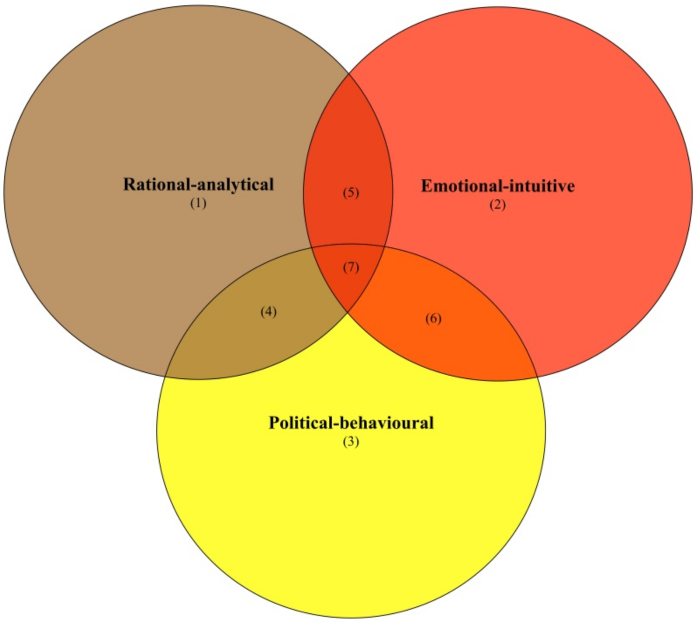
A decision model of technology innovation should also include a political-behavioural approach to the decision. In fact, stakeholders[61] often have an impact on these decision processes through discussions, negotiations, networking, consensus building and/or other social activities that influence the decision. Although sometimes these political process are hidden and/or difficult to unveil (Cray et al. 1991), several authors have argued about the importance of political processes in decision-making (Linn, Man, and Bossink 2013; Jauch and Glueck 1988; Ilori and Irefin 1997; Dill 1975; Gray and Ariss 1985; Narayanan and Fahey 1982; Aram and Noble 1999). Furthermore, the political aspect of decision-making is very important because a "bad" decision can be costly. In fact, an erroneous decision can cost a manager, researcher or politician his/her credibility, promotion, bonuses or even her/his job; backing a wrong alternative can cost a department or political faction its political future; and a serious error can accelerate the death of an organization, a department and even a political

[60]The Swedish General Decision-making Style (GDMS) inventory was created based on a Scott and Bruce (1995) work, and validated with 1441 male military officers on career decision-making and, later, with samples of students, engineers and technicians on important decisions in general.

[61]The term stakeholders is here referred *sensu lato* which includes shareowners, employees, customers, suppliers, lenders and society (Freeman and Reed 1983).

faction. Therefore, a decision model of technology innovation should include a political-behavioural approach, to reflect the impact of these types of activities in the decisions.

A decision model for technology innovation can be inspired by a strategic decision model. In fact, most technology innovation decisions have a strategic[62] nature because they can carry high stakes for those involved, affect the organizations where decisions are made, and/or might have potential effects for large segments of society (Cray et al. 1991). Furthermore, these decisions are strategic to an innovator, a lab, a firm, institutions or even society, because technology innovation can significantly impact them (Gebauer, Worch, and Truffer 2012; Sainio, Ritala, and Hurmelinna-Laukkanen 2012). In 1988 Jauch and Glueck proposed a model for understanding a strategic management decision comprising combinations of three decision-making approaches. Literature review suggests, however, a small adaptation of these three approaches used by the author to capture recent research about decision-making. The following figure depicts three approaches to technology innovation decisions and their interactions:



Source: Adaptation from Jauch and Glueck (1988, 23)

Figure 2.1 – Decisions of technology innovation

The figure presents a model for technology innovation decisions composed of three approaches that can occur in parallel and interact during the decision process: rational-analytical, emotional-intuitive and political-behavioural. There are four main ideas about these approaches:

– First, the rational-analytical approach (see reference 1 in Figure 2.1) describes a rational, conscious, systematic and analytical approach. It is based on all available and feasible alternatives

[62] The term *strategic* is often used in decision-making to indicate important or key decisions made in organizations of all types.

to maximize advantages (Jauch and Glueck 1988). Rationality[63] is the extent to which the decision-making process reflects a desire to make the best decision possible under the circumstances (Dean and Sharfman 1993). This intended rationality (or procedural rationality) is characterized by an attempt to collect the information necessary to form expectations about various alternatives, and the use of this information in the final decision (Dean and Sharfman 1993). It involves setting clear objectives, gathering the facts, generating options, and choosing one that maximizes the objective (Stacey 2011).[64] Rational behaviour can be personified in a decision maker who has:

> Knowledge of the relevant aspects of his environment, …a well-organized and stable system of preferences, and a skill in computation that enables him to calculate, for the alternative courses of action that are available to him, which of these will permit him to reach the highest attainable point on his preference scale. (Simon 1979, 99)

In this sense, the ideal "rational" man behaves and decides only on the basis of propositions that can be consciously reasoned about, rather than on the basis of customs, norms, emotions and beliefs (Stacey 2011). In complex cases, it requires a close collaboration between the analysts and other potential users of the decision. Therefore, a rational-analytical approach to decision-making in technology innovation is characterized by a degree of involvement in collection of information relevant to the decision required during the innovation process. In these cases, the use of indicators signals the presence of rational-analytical thinking during the decision (see next subchapter).

Furthermore, there are some criticisms to this approach: the decision maker is not always alone and is often a part of a multiparty decision situation; decision makers are not rational enough or well enough informed, or information can be too costly to consider all alternatives and consequences of the decision; and decision makers have more goals than just the maximization of objectives (Jauch and Glueck 1988). For example, they can be simply aiming for their decision to suffice, instead of finding the optimal solution. It should also be stressed that the objectives might change, which may undermine the optimal solution. In addition, Herbert Simon developed the concept of bounded rationality in recognition of the restrictive circumstances in which pure technical rationality could be applied (Simon 1979). In fact, most managers take short-cuts: they employ trial-and-error search procedures to identify the most important bits of information in particular circumstances; identify a limited range of the most important options; and then act knowing only some of the potential outcomes of their actions (Stacey 2011). Moreover, the lack of realism of pure rationality was recognized in other ways. In fact, there are numerous occasions

[63] Rationality will not be used in this work in the sense of a sensible, reasonable and sane way of deciding, as opposed to foolish, absurd or extreme ways, as mentioned by Stacey (2011).
[64] The opposite, irrationality, is any behaviour that is not preceded by fixing objectives and weighing up options based on observable facts (Stacey 2011).

where objectives and interests conflict, and the most powerful coalition will decide in a political process (Stacey 2011).

– Second, the emotional-intuitive approach (see reference 2 in Figure 2.1) is based on habit or experience, gut feeling or instinct, and can be guided by unconscious mental processes (Jauch and Glueck 1988; Starcke and Brand 2012). Emotional-intuitive decision makers often consider only a number of alternatives and options because it leads to a better decision than using analytical techniques. When confronted with a problem:

> The machinery of intuitive thought does the best it can. If the individual has relevant expertise, she will recognize the situation, and the intuitive solution that comes to her mind is likely to be correct. (Kahneman 2011, 12)

Furthermore, emotional-intuitive decision makers can also involve other factors or timings that can lead to a better overall decision than simply following what a quantitative model prescribes (Ilori and Irefin 1997).

In innovation contexts, intuition can potentially lead to creative results (Policastro 1999).[65] In fact, intuition is important in tasks related to innovation, which can involve high complexity, short time horizons, ill structured problems and moral evaluations (Linn, Man, and Bossink 2013).[66] Intuition involves the ability to quickly synthesize, integrate information and use decision makers' experience. According to Schoemaker and Russo (1993) intuition can be brilliant when based on extensive learning from past experience, probably reflecting an automated expertise. It seems to be most useful when there are high stakes, a high level of uncertainty, and pressure to make the right decision in a limited amount of time. Some authors prefer to name this type of approach only as emotional, which excludes the enriching aspect of intuition important to innovation. Therefore, it seems more appropriate to use the label emotional-intuitive because it not only captures the emotional nature of the approach, but also involves the intuition concept often linked to innovation contexts.

This approach has been criticised because: it does not effectively use all tools available to decide; and the use of a rational model instead ensures that proper attention is given to consequences of decisions before significant mistakes are made (Jauch and Glueck 1988). According to Policastro (1999) intuitions are not infallible, since they are like rough estimates, which necessarily entail some margin of error. A significant danger exists because most individuals, when, for example, faced with a difficult question, "often answer an easier one instead, usually without noticing the substitution" (Kahneman 2011, 12).

[65] The term intuition can be defined as a tacit form of knowledge that guides decision-making in a promising direction (Policastro 1999).
[66] The term has been also used to capture emotions such as people relying on "gut feeling" to make decisions, a "strong feeling about it" or the self-righteous "people just know that they are right" (Schoemaker and Russo 1993, 10).

- Third, the political-behavioural approach (see reference 3 in Figure 2.1) is based on the pressure of different stakeholders and their impact on the decision process. During a decision, stakeholders can be suppliers, trade unionists, owners, workers, competitors, colleagues, experts, governments or other institutions (e.g. parliaments, committees and agencies.). The political-behavioural approach implies that there is a limited number of choices available as determined by the organization and institutional arrangements. In this approach, decisions are made when several stakeholders agree that a solution has been found, through adjustments and negotiations. The approach assumes that the real decision makers must consider a variety of pressures from other people affected by their decisions, and likewise reflect whether the decision can be implemented politically (Narayanan and Fahey 1982; Ilori and Irefin 1997; Jauch and Glueck 1988). In fact, an organization has to interact with a variety of stakeholders, who hold different degrees of power, and who give an individual or an organization something and expect something in return. Examples of these interactions can occur during negotiation activities, consensus-building, networking, workshops, discussions, coalition-building, compromise and/or other type of social activities that can influence the decision-making process. Naturally, the more power stakeholders have, the more influence they will exert over decisions, because organizations are more dependent on them (Jauch and Glueck 1988). Therefore, decision makers meet stakeholders' demands through political compromise, mutual adjustments and merging competing demands to create a coalition of interests that will support the decision.

  Decision-making can be made in a process of mutual influence, which may involve actors with different, sometimes even opposing, interests. In fact, strategic decisions are often made in a social process of interaction of different actors and groups. Some authors stressed that, in reality, when decisions are made, it is the product of social relations that matter, through networking activities, different forms of social pressure, expression of values and norms, etc. According to Perri 6 (2002), decision makers only use a certain amount of knowledge when making a decision, and their judgments are rather dependent on where actors are socially situated and integrated. Perri 6 (2002) supports the view that forces of social regulation and social integration exist, and shape the individuals' decisions. These forces can be used to explain how several social actors use information, behave and judge. The result of social relations acts upon individuals, both consciously and unconsciously, constraining and guiding them throughout their decision-making. The term "social relations" is a central concept of sociology and here it is used broadly to refer to the multiple ways people are connected and influence one another (Hall and Lamont 2013). In this study, the term relates to all social activities that can influence a technology decision, such as networking activities, hierarchical or peer pressures, marketing activities, expression of values and norms, discussions, etc.

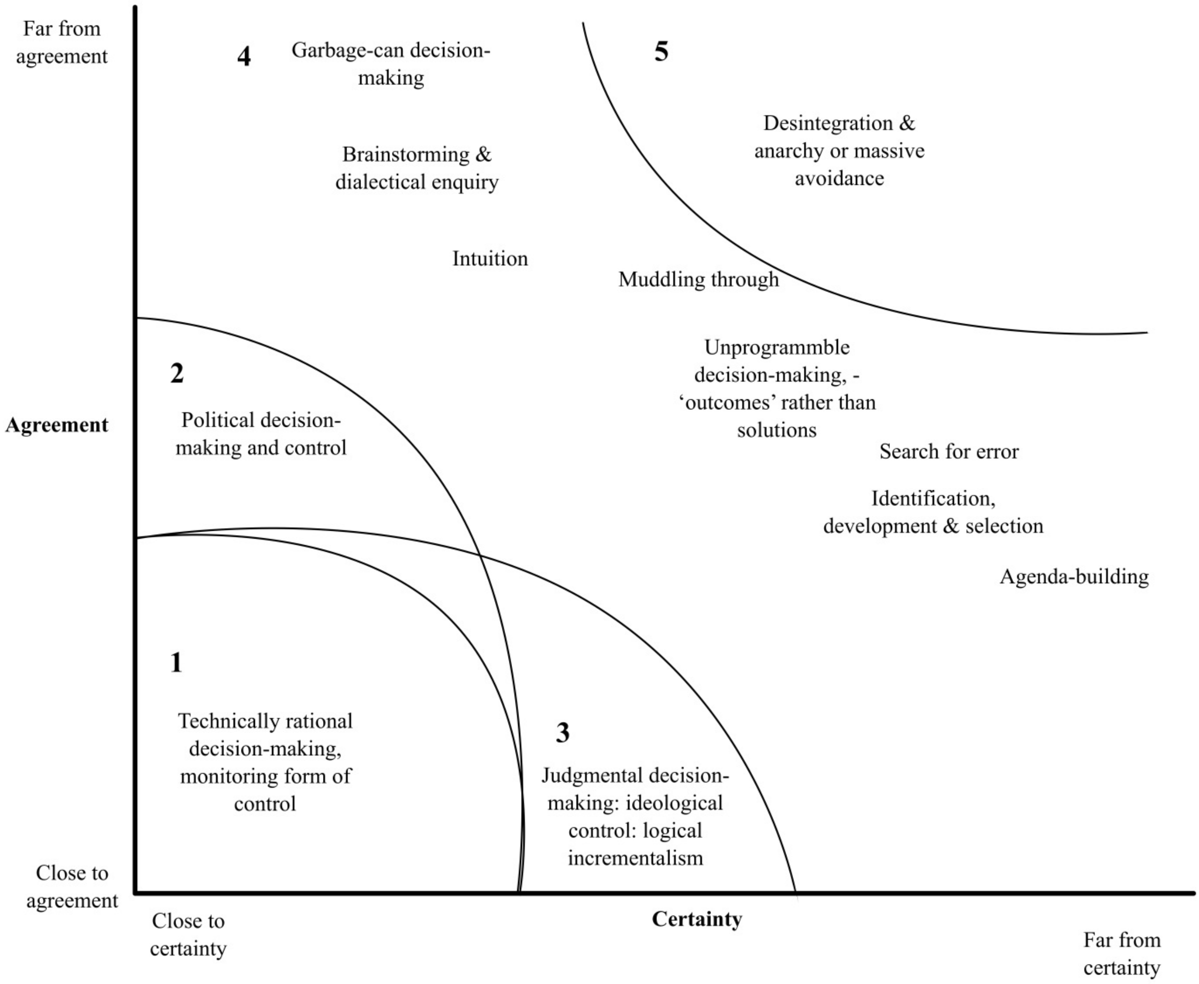
  This approach has been criticized for implying that institutions play a real role in limiting the choices available to a decision maker, assuming decision makers accept and recognize the power of stakeholders. However, decision makers might pretend to negotiate, and will not accept mutual adjustments and real negotiations. Furthermore, the approach unrealistically implies that all decision makers previously consider whether the decision outcome might be implemented politically. Other criticism to this approach include the damaging consequences of decision-making based on interests, seeking a lower common denominator in the decision, limiting decisions to incremental changes, disregarding information and evidence and the possibility of paralysis in the decisions process.

- Fourth and last, the use of two or three approaches in combination can occur in a decision process. In fact, different approaches may need to be combined to different extents to explain the decision-making process (Linn, Man, and Bossink 2013). In some contexts, the rational-analytical component is very large and, in others, the emotional-intuitive can dominate, or decisions can be made mostly according to political realities. For example, the rational-analytical and political-behavioural approaches can interact (see reference 4 in Figure 2.1) in a process simultaneously high/low in politics and high/low in rationality. In these cases it may be rational to behave politically, or it may be political to behave rationally (Dean and Sharfman 1993; Linn, Man, and Bossink 2013). Furthermore, politics may frequently obstruct the flow of information, particularly in high-velocity environments where timely and accurate information is only shared amongst selected members of the group (Eisenhardt and Bourgeois III 1988; Perri 6 2002). In these cases, political behaviour may block the rational assessment of a situation, as decision makers are not able to take into consideration all alternatives. In addition, the interaction between rational-analytical and emotional-intuitive approaches exists (see reference 5 in Figure 2.1), but is based on assumptions by researchers in the literature who, according to Linn, Man, and Bossink (2013), failed to provide rigorous empirical data. In addition, the interaction between political-behavioural and emotional-intuitive approaches is plausible (see reference 6 in Figure 2.1) but, according to the latter authors, there are no empirical studies about this interrelation. Moreover, the latter authors found that a process dominated by rationality and supported by intuition yields more effective political processes (see reference 7 in Figure 2.1). In the same train of thought, Jauch and Glueck (1988) stated that decisions can be made using the three approaches: a rational-analytical approach combined with an emotional-intuitive consideration in light of political realities. For example, managers were found to purposely blend behavioural, political and formal analytical processes together to improve the quality of decisions and implementations (Stacey 2011).

The degree to which each approach dominates the mind of the decision maker can vary significantly due to a diversity of factors. These factors can range from those related to the *context* of the decision to the personal *characteristics of the decision maker* (Meijer, Hekkert, and Koppenjan 2007). The personal characteristics can vary significantly, but the demographic characteristics and in particular the person's educational level can significantly affect decisions, according to Musso and Francioni (2012). Higher levels of education facilitate the use of rational decision-making, whereas lower levels tend to lead to the use of intuition. Other personal characteristics of the decision makers exist but will not be studied in this work.[67]

The *context* of the decision can significantly influence the selection of approaches to be used by the decision maker. This contextual factor includes the political environment, the economic conditions of a decision, and the type of organization where the decision occurs. The organisational literature proposes three different types of structures for complex decision-making: the functional organisation, the matrix organisation, and the organisation by project (Aubry, Hobbs, and Thuillier 2007). Another important component of the organizational context is level of qualifications of the team involved in the decision. In fact, qualifications play a role when selecting an approach to make a decision (Meijer, Hekkert, and Koppenjan 2007). The qualifications are particularly important because the team has to deal with different levels of uncertainty, agreement and complexity present in technology innovation decisions. The following figure captures the contexts of decisions according to the degree of uncertainty and agreement associated with each decision.

[67] This study requires more resources than the ones presently available. More information about other personal characteristics can be found in the works of Musso and Francioni (2012) and of Meijer, Hekkert, and Koppenjan (2007).



Source: Stacey (1996, 47).

Figure 2.2 – Zones of decision-making by certainty and agreement

The figure shows that when conditions are close to certainty (zone 2), agreement (zone 3) or both (zone 1), the dominant management styles and theories based on planning and power relations can be employed (Aram and Noble 1999). In other words, in these zones all approaches can exist or co-exist. However, when a team have to operate far from both certainty and agreement (zone 4), decision-making becomes more intuitive, hard to programme, and possibly a messy discontinuous process (Aram and Noble 1999). This vast central region (4) can be named the zone of complexity because it is a region of high creativity, innovation, and change to create new modes of operating (Stacey 1996). There are several methods that can be applied in zone 4, when moving towards uncertainty and disagreement. In zone 4 the latter author depicted two interesting examples to be considered in more detail, because they provide theoretical ground for understanding various differences between decision-making processes:

1) "Garbage can" decision-making suggests that an organization is seen as a collection of solutions looking for appropriate problems in the garbage (Cray et al. 1991). It suggests that (chaotic) human organizations tend to produce many discarded "solutions" due to an absence

of appropriate problems. The main idea is that the substance of the problem is irrelevant except for the stakes that can be attached to it by various interests, according to the authors. Problems may eventually appear for which a search in the garbage can might provide fitting solutions. The idea was developed in reference to explanations/interpretations of behaviours in decision situations that appear to contradict classical theory of rational decision (Cohen, March, and Olsen 1972). In fact, the garbage can idea was influenced by extreme cases of uncertainty in decision environments (i.e. higher education institutions) that would trigger responses, which, from a distance, appear "irrational". According to Cray et al. (1991, 231), the garbage can model/method reveals the importance of political aspects expressed by the "internal wrangling and external negotiation often present in strategic decision-making".

2) "Muddling through" decision-making is a method described in the classic article by Charles Lindblom (1959), highlighting a long-standing division in public administration approaches. "Muddling through" comes from the British expression in "muddling through somehow". The expression means the act of facing a complex bureaucratic decision process and "getting the job done". At the time, the dominant approach to public administration followed the belief that scientific analysis could solve the political problems faced by public administrators, putting strong faith in rationalism through various forms of rational or technical analysis. According to Lindblom, a rational approach is often not possible, and he argued that the frequently despised political manoeuvring characteristic of administrative decision-making might not be as bad as it appears to many.

In zone 4, where garbage can and muddling-through can occur, control is decentralized and contradictory forces need to be implemented to avoid the destructive forces and disintegration of the system represented in zone 5 (Aram and Noble 1999). Zone 5 represents an area with high levels of uncertainty and disagreement in organizations, where disintegration, breakdown or anarchy can occur if avoidance measures are not implemented (Stacey 1996).

Conditions of uncertainty, furthermore, might be connected to situations where only implicit consequences are given, or when the entirety of the information cannot be processed by an individual. If uncertainty exists to a moderate degree then both emotional-intuitive systems and the rational-analytical may act in concert (Starcke and Brand 2012). A rational-analytical approach can be useless if the decision faces significant uncertainty (Starcke and Brand 2012). Nevertheless, rational-analytical approaches can still promote decisions to develop new products. According to Linn, Man, and Bossink (2013, 5-6) rational-analytical approaches can be helpful "when technological uncertainty is high, intuitive judgments may differ considerably and politics may lead to the continuation of unsuccessful R&D projects". A typical example of decisions under uncertainty is the case of emerging technologies[68] such as nanotechnology, synthetic biology or brain-computer interfaces. In these cases, the high degree of uncertainty surrounding the

[68] I.e. technologies that are still in an early phase of development (van Merkerk and Smits 2008).

technologies signifies both the large variety of opportunities that a new technology has to offer, and a threat of not knowing what comes next and not being able to *ex ante* determine the success or failure of a technological path (Meijer, Hekkert, and Koppenjan 2007, 5836).

It can generally be concluded that, on one hand, decisions can be made in knowledge-intensive environments where information gathering and evaluation occurs extensively. In cases where information is useful, a rational-analytical approach can lead to or help in a decision. On the other hand, information about product concepts and impacts is often insufficient in the early phases where innovative ideas can occur. In this case, decisions can be based on judgments and incomplete evaluations involving not only many actors and interactions, but also politics, conflicts, confusions and other noise (Kihlander and Ritzén 2012). In short, decision-making in technology innovation is seldom about correct answers, but mostly satisfactory answers that eliminate bad alternatives rather than the best possible one (Kihlander and Ritzén (2012).

In sum, a decision model for technology innovation will be used to understand the relevance of the context of the decision (and the process of construction of evidence). The context will be investigated in terms of political setting, economic environment and organizational structure and competences. The personal characteristics of the decision maker will not be taken into consideration in this study.

2.2.4 Types of decisions of technology innovation

There are four types of technology decisions that can occur in a decision process of technology innovation. In these contexts there can be, first, decisions about the acquisition of new equipment and/or technology. This type of decision can involve public as well as private researchers judging about economic and financial impact of the decision. However, these decisions can also comprehend significant strategic aspects about the future of the organization. For example, the acquisition of a powerful jet printer for a public laboratory requires considerations beyond the financial cost, and includes technology characteristics, availability of human resources, skills to operate and/or the relationship with the suppliers. Furthermore, policymakers may be involved in this type of decision to promote R&D&I activities associated with significant acquisitions, often named compensatory measures. In fact, these acquisitions can be related to the military (e.g. submarines, tanks and frigates), healthcare (e.g. MRI[69] and robots), or communications (e.g. cloud computing services and telecommunications). Therefore, decisions about the acquisition of new equipment/technology can be significantly important to a research laboratory, a department, a company involved in R&D&I activities, and in some policy decisions.

[69] MRI is the acronym of Magnetic Resonance Imaging.

Second, innovations can occur after decisions about the development of a new product and/or a technology. Companies involved in R&D&I activities as well as (public) research laboratories or departments are often involved in these types of decisions. These decisions are strategic for the company or laboratory because they will set up the direction of the forthcoming works, and significantly impact those involved at all levels. In a company, the outcome of this decision can lead to success or significant losses. In a laboratory, it can lead to a successful product/technology or to the abandonment of activities in the field after a significant investment. In addition, sometimes policymakers decide upon the development of a new product and/or technology. These decisions can include the decision to integrate more security features in national passports, the introduction of new ticketing in public transports, or the development of national technology related to the military or biological hazards. Therefore, decisions of development of product/technology can involve public researchers, companies with R&D&I activities, as well as policymakers.

Third, innovations may be the outcome of decisions about the acquisition of intellectual property. In fact, companies or (public) research institutions can involve themselves in decisions to buy patents, trademarks, industrial designs or copyrights. Like the previous decision types, this decision can contain significant strategic aspects for the future of the organization. This type of decision can involve financial considerations, but also important elements related to existing skills within the organization and human resource management. Therefore, decisions about acquisition of intellectual property can involve companies or other research institutions in strategic considerations.

Fourth and last, there may be decisions about innovation, technology or industrial policy. These types of decisions can produce effects in the innovation system and, consequently, in technology innovation, as discussed earlier. For example, a decision to introduce tax benefits can impact the amount of R&D&I activities in companies. In another example, a decision to increase admissions into science and engineering degree programmes impacts the future quality of the labour force available to (public) departments/laboratories and companies. Therefore, policy decisions can involve a broad range of areas of intervention, and may have significant impact on technology innovation.

A technology innovation decision is expected to be embedded in elements of complexity and uncertainty: First, technological innovation is often associated with complexity[70] (Chapman and Hyland 2004; Rycroft 2007; Waelbroeck 2003; Wonglimpiyarat 2005). In the technology innovation context, complexity can be understood as components that, integrated together, cause difficulties for the transformation into successful products/processes (Wonglimpiyarat 2005). Complexity in innovation has been associated with experiences where information is incomplete or ambiguous, and the consequences of actions are highly unpredictable (Aram and Noble 1999). In these contexts, complexity is contained in technologies, products, customer interfaces and organizational setups (Chapman and Hyland 2004). In these situations, muddling through or garbage can models will

[70] "Complexity" is the state or quality of being intricate or complicated ("Complexity" Oxford Dictionaries Online. Last accessed in 21/12/2014).

probably be more useful for understanding the decision process, as discussed earlier. Second, technological innovation is also often associated with uncertainty[71] (Böhle 2011; Jalonen and Lehtonen 2011; Fusari and Reati 2013; Meijer, Hekkert, and Koppenjan 2007; Dosi 1982; Nelson and Winter 1977; Carbonell and Rodríguez-Escudero 2009; Sainio, Ritala, and Hurmelinna-Laukkanen 2012). Innovation involves uncertainty in an essential way because "different people, and different organizations, will disagree as to where to place their R&D chips, and on when to make their bets" (Nelson and Winter 1977, 47). Although uncertainty might motivate an individual to seek information, the "information about innovation is often sought from near-peers, especially information about their subjective evaluations of the innovation" (Rogers 2003, xix). This exchange of perceptions about a new idea occurs through a convergence process involving interpersonal networks (Rogers 2003). There are numerous types of uncertainty associated with the innovation process, although technological, market and regulatory uncertainties have an established status (Jalonen and Lehtonen 2011; Sainio, Ritala, and Hurmelinna-Laukkanen 2012).[72] Therefore, complexity and uncertainty are central elements of decisions in technology innovation.

[71] "Uncertainty" can be defined as the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probabilities of these alternatives (Rogers 2003).

[72] But many more can be identified. For example, Carbonell and Rodríguez-Escudero (2009) considered only two aspects of uncertainty: technology novelty and technological turbulence. In their study on innovation in biomass gasification projects in the Netherlands, Meijer, Hekkert, and Koppenjan (2007) argued that technological, political and resource uncertainty are the most dominant sources of perceived uncertainty influencing entrepreneurial decision-making.

2.3 CONCLUSION

This chapter discussed the need to conduct research to study the role of indicators in the decision process of technology innovation. The first subchapter argued that more research is needed about the role of indicators in these decisions. The second subchapter developed the main concepts needed to conduct the research. This third and last subchapter intends to summarize the research questions and the hypotheses formulated, and to identify the main concepts to be articulated by the hypotheses.

The literature reviewed in the first subchapter indicated the need to conduct research to describe and explain the role of indicators in decisions of technology innovation. In fact, a gap was detected in the literature of innovation and technology assessment about the influence and role of indicators in this type of decision. It is important to address this gap because indicators are often important elements of these studies. Thus:

- The research will first answer the question: (*Q1) Is the use of indicators different from their influence in decisions of technology innovation made by the three innovation groups?* The hypothesis formulated is: (*H1) Despite their high level of use, indicators have low influence in decisions of technology innovation made by the three innovation groups*. The concepts needed to articulate this hypothesis (reviewed in both the first and second subchapter) include indicators, use of indicators, influence of indicators, decision-making, technology innovation, and innovation groups.
- The discussion in the subchapter 2.1 also pointed to the need to conduct research in order to answer the question: (*Q2) What is the role of indicators in decisions of technology innovation by the three innovation groups?* The hypothesis formulated is: *(H2) Indicators have a symbolic role in the decisions of technology innovation made by the three innovation groups.* There are several important concepts needed to articulate in this hypothesis such as indicators, the role of indicators (instrumental role, symbolic role or no role), decision-making, technology innovation, and innovation groups.
- Last, the discussion also identified a third research question: (*Q3) How are indicators used in decisions of technology innovation?* There were four possible hypotheses to be tested: *(H3) The type of decision helps to explain how indicators are used in decisions of technology innovation; (H4) the phase of decision helps to explain how indicators are used in decisions of technology innovation; (H5) the context helps to explain how indicators are used in the decisions of technology innovation;* and *(H6) the process of construction of evidence helps to explain how indicators are used in decisions of technology innovation.* These hypotheses contain same concepts of the latter questions (e.g. indicators, technology innovation, decision-making, and innovation groups), as well as news ones such as the type of decision, phase of decision, context

of decision (political, economic and organizational) and process of construction of evidence. The latter two concepts will be articulated through the decision-making model of technology innovation and the network theory described earlier. These two theoretical concepts will help to understand the influence of the context and the process of construction of evidence in the way indicators are used to make decisions of technology innovation.

3. METHODS

This chapter discusses the methods selected to test the hypotheses described previously. Methods refer to the range of techniques available to collect evidence about the social world. They are tools or lenses to be applied to different kinds of research questions researchers seek to address. The use of quantitative, qualitative or combined methods relies on epistemological choices derived from different scientific traditions.[73] According to Alasuutari, Bickman, and Brannen (2008), there is presently an increased permissiveness in this division: on one hand, researchers are willing to learn more about the possibilities of applying survey methods and statistics to their analysis; on the other hand, different methods of analysing talk, texts and social interaction amplify the lenses available to study social reality from different points of view. In this context, different methods can be combined not only to gain from individual strengths of each method, but also to compensate for the particular faults and limitations of a single method, overcome biased interpretations in research, and provide a complete overview of the matter under investigation (Henn, Weinstein, and Foard 2009). The selection of methods to collect data depends on the nature of the inquiry and the type of information required. In this study, a combination of methods was used to answer the three research questions. The following table summarizes the hypotheses formulated earlier, the variables at stake, and the methods and measures employed to test them.

[73] There are two dominant epistemological positions for what counts as knowledge within the social sciences and the best way to acquire this knowledge: the positivistic approach and interpretivism (Henn, Weinstein, & Foard (2009). Positivism is usually associated with techniques such as experiments and surveys, often called quantitative methods. Interpretative approach usually includes qualitative techniques such as participant observation, in-depth interviewing, focus-group interviewing, projective interviewing and personal documentary analysis.

Table 3.1 – Summary of the analytical model

Hypotheses	**Independent variable(s)**	**Dependent variable**	**Method**	**Measurement**
(H1) Despite their high level of use, indicators have low influence in decisions of technology innovation made by the three innovation groups.	Use of indicators, and Influence of indicators in the decision	Innovation group (researchers, business R&D&I leaders, and policy makers)	Survey (65 self-administered questionnaires and 26 standard interviews)	Researchers survey (questions 2 and 7)
				Business survey (questions 2 and 7)
				Policy makers survey (questions 2 and 9)
(H2) Indicators have a symbolic role in the decisions of technology innovation made by the three innovation groups.	Role of indicators (Instrumental, Symbolic, and No role)	Innovation group (researchers, business R&D&I leaders, and policy makers)		Researchers survey (questions 2 and 7)
				Business survey (questions 2 and 7)
				Policy makers survey (questions 2 and 9)
(H3) The type of decision helps to explain how indicators are used in decisions of technology innovation.	Type of decision (Acquisition of equipment/technology, Development of product/technology, acquistion of intellectual property, and Policy design)	Influence of indicators in the decision, role of indicators, and type of indicators		Researchers survey (questions 1, 4 and 7)
				Business survey (questions 1, 4 and 7)
				Policy makers survey (questions 1 , 3, 7 and 9)
(H4) The phase of decision helps to explain how indicators are used in decisions of technology innovation.	Phase of decision (before and after)	Influence of indicators in the decision, and type of decision		Researchers survey (questions 1, 3 and 7)
				Business survey (questions 1, 3 and 7)
				Policy makers survey (questions 1, 4 and 9)
(H5) The context helps to explain how indicators are used in the decisions of technology innovation.	Context (political, economic and organizational)	Influence of indicators in the decision	2 Case studies with Social Network Analysis	Case study questions (questions 1 to 9) + Sociograms, factions, core-periphery, measures of general centralization, density, connectedness and compacteness, and individual Eigenvector centrality and betweeness (questions 6, 7, 8 and 9)
(H6) The process of construction of evidences helps to explain how indicators are used in decisions of technology innovation.	Process of construction of evidence	Influence of indicators in the decision		Case study questions (questions 10 to 14)

Table 3.1 reveals six main ideas about the analytical model that will be used in this research:

- Hypothesis 1 contains two independent variables (e.g. use of indicators and influence of indicators in the decision) and one dependent variable (e.g. innovation group). The measurement of the variable "use of indicators" is made in Question 2 of the survey (more details about the survey can be found in subchapter 3.1 and in the Annex 1 – Questionnaires). In fact, Question 2 ascertains whether indicators were used in the decision.[74] Furthermore, the measurement of the variable "influence of indicators in the decision" is made in Question 7 of the survey put to researchers and business, and in Question 9 of the survey put to policymakers. In fact, this question asked whether the indicators were more important than social relations in the decision.[75] The contrast between these two questions allows testing Hypothesis 1 by identifying the difference between the levels of use and the real influence indicators had on decisions by innovation group.
- Hypothesis 2 contains one final variable (e.g. role of indicators) and one dependent variable (e.g. innovation group). As described in Chapter 2, the role of indicators is divided into three categories: an instrumental role, a symbolic role or no role in the decision at all. These categories were identified using the same aforementioned questions (2 and 7) of the survey for researchers and business, and Questions 2 and 9 of the survey for policymakers. In fact, an analysis of the use and non-use of indicators as well as their influence in the decision allows the categorization of the role indicators in the decisions. The categorization tests if indicators have a symbolic role in decisions by innovation group (see subchapter 3.1 and in the Annex 1 – Questionnaires for more details).
- Hypothesis 3 contains one independent variable (e.g. type of decision) and three dependent variables (e.g. influence of indicators in the decision, role of indicators, and type of indicators). As described in Chapter 2, there are four types of decisions (i.e. acquisition of equipment/technology, development of product/technology, acquisition of intellectual property, and policy design). The measurement of this variable - type of decision - was made in Question 1 of the survey, where respondents had to describe the type of decision they were referring to. The measurement of the variable "influence of indicators in the decision" was made in interviews and Question 7 (or 9 for policymakers), where respondents were asked whether the indicators were more important than social relations to the decision.[76] The measurement of the variable "role of indicators" was made during the same questions (2 and 7 of the survey for researchers and business, and Questions 2 and 9 of the survey for policymakers). The analysis of both the use and non-use of indicators, as well as their influence in a decision, allows the categorization of the role of indicators in a decision. Last, the measurement of the variable "type of indicators" was made in Question 4 of the survey

[74] It was possible to answer yes and no in this closed compulsory question. The selection of the latter option required respondents to proceed to question six (see Annex 1 – Questionnaires).
[75] In this closed question respondents had to answer yes or no.
[76] It was possible to answer yes and no in this closed compulsory question.

for researchers and business, and Questions 3 and 7 of the survey for policymakers. The question(s) inquired of the respondents about the types of indicators used in decisions. Thus, the relevance of the type of decision to explain the way indicators are used was tested with the combination of information collected in the survey about the type of decision where indicators were influential, the role of indicators by type of decision, and the type of indicators by type of decision (see subchapter 3.1 and in the Annex 1 – Questionnaires for more details).

- Hypothesis 4 contains one independent variable (phase of decision) and two dependent variables (influence of indicator in the decision and type of decision). The interviews and the survey (Question 3 for researchers and business, and Question 4 for policymakers) inquired about the phase of decision. There were three options available to identify the intensity of the use before and after the decision: never, sometimes and many times.[77] As mentioned, the measurement of the variable "influence of indicators in the decision" was made in Question 7 (or 9 in the case of policymakers), where respondents were asked whether indicators were more important than social relations to the decision.[78] The measurement of the variable "type of decision" was made in Question 1 of the survey, where respondents had to describe the type of decision they were referring to. Thus, the relevance of the phase of decision to explain the way indicators are used was tested with the combination of information collected about the phases of decision in cases where indicators were influential in the decision and in different phases by type of decision (see subchapter 3.1 and in the Annex 1 – Questionnaires for more details).

- Hypothesis 5 contains one independent variable (context of decision) and one dependent variable (influence of indicators in the decision). Questions 1 through 9 of the case studies allowed a description of the context in terms of their most relevant elements: political environment, economic circumstances and organizational context (more details in subchapter 3.2). The latter was complemented by a social network analysis of the organizational structures that made the decisions. In fact, questions 6, 7, 8 and 9 of the case studies allowed the mapping of those structures through the construction of sociograms[79] and identification of factions and core-peripheries. The social network analyses also allowed for comparing the two structures with measures of general centralization, density, connectedness and compactness, and individual Eigenvector centrality and betweenness (see subchapter 3.2 for more details). In sum, the analysis of the information collected in two case studies allows intensive, detailed and in-depth research about the context of the decisions to test its relevance in understanding the way indicators were used in the decision.

[77] A three-point Likert scale was appropriate to inquire about the behaviour of the decision maker, according to Lehmann and Hulbert (1972).
[78] It was possible to answer yes and no in this closed compulsory question.
[79] A sociogram is a sociometric chart plotting the structure of interpersonal relations in a group situation ("Sociogram." Last accessed in 21/12/2014. http://www.merriam-webster.com/dictionary/sociogram).

- Hypothesis 6 contains one independent variable (process of construction of evidence) and one dependent variable (influence of indicator in the decision). The two case studies collected information about the evidence and indicators used in the decision (Question 10), their purpose (Question 11), controversies (Question 12), phase of the decision (Question 13), and other details important to understand the way evidence and indicators were introduced in the decision process (Question 14). The analysis of this information allowed a comprehensive view of the process of construction of evidence to test its relevance in understanding the way indicators (and other evidence) were used in the decision process (subchapter 3.2 for more details).

3.1 SURVEYS

Surveys were designed to collect data to test the hypotheses. Surveys are a method of gathering similar information from a large number of people at the same time with either a descriptive and/or explanatory nature (Henn, Weinstein, and Foard 2009). A "descriptive" survey was used to describe a sample in terms of proportions and percentages of people (Punch 2006, 75). The preparation of the surveys included twelve exploratory interviews to formulate and calibrate the questions. These exploratory interviews were qualitative and in-depth, with significant latitude to discuss the topic of the use of indicators and decision-making. These interviews were prepared based on literature review and analysis of official documents and other grey literature. Interviewees were composed of experts identified as having sound knowledge of and experience in the use of indicators and decision-making. The interviews occurred in Germany, Switzerland and Portugal, were developed between October 2011 and January 2012, and lasted from one to four hours.

After, the surveys were prepared for launch through self-administered questionnaires and standardized interviews. The questionnaires and interviews employed fixed formats for questions and answers to ensure consistency of data collection (Leeuw 2008). The difference between the two techniques is the presence of the interviewer and the ability to see the questions. The presence of an interviewer, in particular, can be a doubled-edged sword to a survey, since it can increase the proper implementation of the questions, reduce non-response and improve data quality; but it can also influence responses and cause unwanted interviewer effects, especially when sensitive issues are at stake (Leeuw 2008). Consequently, this survey was conducted with a balanced number of questionnaires (65) and interviews (26) to improve response rate and to minimize interviewer effects.

It should be stressed that no bias was found in the answers about the use of indicators in the survey. There were five precautionary measures to prevent bias: First, bias towards a positive answer regarding the use of indicators was avoided by separating the question of use from the question of influence of indicators. In fact, the separation of these questions forced the respondent to consider and indicate with precision when indicators were used, which and what for, and the importance of other individuals in the decision before evaluating the influence of indicators. Second, the survey was preceded by a clear explanation that the objective of the work was to determine how the decisions were made, not merely to detect the use of indicators. Third, to deter any partiality for answering affirmatively, the second question of the questionnaires and interviews (related to the use of indicators) was followed by explicit instruction to continue answering in question number 6 in the case of a non-use of indicators during a decision (see next sub-section). Fourth, the online questionnaires were anonymous to discourage any feeling of pressure to answer affirmatively. Fifth, the interviews were confidential (and anonymized), which discouraged fabricating or strengthening of responses per an anticipation of desired answers (see section 3.1.2). Therefore, there is little or no ground to think that there was bias towards answering affirmatively towards the use of indicators.

The samples for the survey were only composed of individuals who were involved in confirmed technology decisions and belonged to the innovation groups. The samples were created using non-probability sampling methods (Saumure and Given 2008) in the following way:

- The samples of business R&D&I leaders and public researchers were selected using purposive criterion sampling (Palys 2008), and were based on the 2010 National R&D Survey.[80] There were three criteria: first, the presence of a scientific leader in an R&D project in 2010; second, the existence of expenditures in equipment (i.e. instruments, equipment or software equal to or higher than 1500€ for business R&D&I leaders and 3000€ for researchers); and third, the research/innovation team needed to have at least one PhD (full-time equivalent). In this way, the criteria confirmed that a real technology decision was made in one existent R&D&I project with a minimum financial effort (the National R&D survey captures efforts that are excessively low to worth analyses). The magnitude of the financial effort selected is the minimum acceptable for a company or a laboratory to run for a year with R&D&I project. Furthermore, the criteria also guaranteed that the research team had proper skills to conduct a sound R&D project (the National R&D survey captures contexts where the levels of skills are excessively low to worth analysis). The samples were considered significantly representative because they were only composed of scientists (or equivalents) who made a confirmed technology decision in a reliable R&D&I environment. In these contexts, there were 57 leaders of R&D&I departments of companies in the National R&D Survey, and 36 responses were received corresponding to a response rate of 63%.[81] There were also 78 public researchers that met the criteria, and 31 responses were received corresponding to a response rate of 40%.
- The sample of policymakers was created using snowball sampling (Morgan 2008) for two main reasons: there were no other sources for locating the members of this population; and almost all

[80] The National R&D Survey (named IPCTN) is a reliable long-term survey that captures with detailed data any existing projects, researchers and companies involved in R&D in Portugal. The survey has internationally comparable standards, a reliable quality, is based on the Frascati Manual and is regularly checked by OECD, Eurostat and the National Institute of Statistics.
[81] The 2010 national R&D survey database detected 59 companies in the country that met the criteria. The business questionnaire was sent, however, only to 57 due to the closer of 2 firms.

members knew each other. The initial set of participants (serving as informants about potential participants) was significantly diverse and was complemented by Google searches to avoid possible bias. Two successive waves of snowballing assured a more representative sample (Schutt 2008). The final sample was composed of the vast majority of individuals directly involved in innovation policy decisions in the period 2005-2011 in the country. The sample was considered significantly representative given the reduced number of individuals involved in innovation policy at the time. In this context, there were 59 individuals listed as being definitely involved in innovation policy, and 24 responses were received corresponding to a response rate of 41%.[82]

The response rates obtained for the three groups were considered significant by normal standards in social research, where they are traditionally lower (cf. Shih and Fan 2009 and Baruch 1999). Furthermore, to account for effects on response rates, there were three personalized email campaigns with three reminders each, and personal contacts to sensitize individuals to answer, from February 2012 to mid-June 2013.[83] No differences were detected between online replies and direct answers. In addition, the answers were not compulsory by law, there were no economic incentives to answer, and the questionnaires were not part of the national statistical system. Thus, only volunteers could reply to the survey. Moreover, the online answers did not allow for establishing any relationship with specific individual technology decisions. Finally, the questions of the questionnaire were short (it took an average of five minutes to answer all of them), with closed questions (with two exceptions for the policymakers group) and related to concrete technology options (see below).

3.1.1 Self-administered questionnaires

The work involved self-administered questionnaires, as mentioned previously. They are a data collection technique carried without the presence of an interviewer and can be conducted as web questionnaires, postal surveys or a psychological surveys (Leeuw 2008). In this work, the survey included three online questionnaires, similar but not identical to each other, in order to adjust to the context and differences of each innovation group. The questionnaires addressed representatives of the three Portuguese groups under analysis, collecting 65 answers (out of an overall 91 surveys collected) from February 2012 to June 2013. The difference between the two questionnaires of researchers and business R&D&I leaders was considerably minor. In fact, it consisted only of small adaptations of the text to the context of each innovation group. There were, however, two distinct features in the case of policymakers. These features were based on the need to understand in detail the use of indicators in the decision of each policymaker. First, a pre-question was introduced to identify the position occupied during the technology policy decision.[84] Second, three questions were added to understand

[82] The sampling technic allowed the identification of 65 policymakers but, after a significant number of attempts to locate the policymakers, 6 were considerable unreachable.
[83] See Fan and Yan (2010) for methodology of on-line questionnaires.
[84] The options were Minister, Secretary of State, Political advisor to the Minister, Political advisor to the Secretary of State, Consultant; Director-General, Civil servant, Parliamentarian, City Mayor and Other position.

the level of knowledge about the indicators used in the policy decision, namely: (i) "Please name the indicators used or recommended to make the decision"; (ii) "Did you use other type of information in the decision (e.g. studies, advices or sectorial information)?"; and (iii) "In case you used other type of information, please name indicators that were used". Nevertheless, all questionnaires (and standardized interviews) shared the same structure composed by nine parts (see Annex 1 – Questionnaires):

1) The questionnaires inquired about type of technology decision related to the adoption and/or investment in technology (choosing the most important one for his/her activity). In this closed compulsory question, it was possible to choose (as response) between acquisition of product/technology, development of product/technology, acquisition of intellectual property rights, and conception of policies (e.g. ideas, programmes, measures, actions and projects).

2) The questionnaires inquired whether any indicators were used in the decision, such as indicators related to financial, technical, organizational aspects, among others. In this closed compulsory question, it was possible to answer yes or no. The selection of the latter option required respondents to proceed to question six.

3) The questionnaires inquired about the intensity of the use of indicators in the decision. In fact, in a closed question, there were three options about the intensity of use before the decision: never, sometimes and many times. The same question was asked after the decision, with the same options. The three-point Likert scale was enough for inquiring about the behaviour of these groups (Lehmann and Hulbert 1972).

4) The questionnaires asked to select up to three typologies of indicators used in the decision. The twelve typologies available were: (a) Use of technology by partners; (b) Use of technology by competition; (c) Suppliers (existence of an easy relationship, their characteristics, their type, etc.); (d) Technical characteristics of the technology collected over the internet, brochures, exhibitions, public events, etc.; (e) Technical characteristics of the technology collected through intermediaries such as R&D centres, technology centres, consulting services, industry associations, etc.; (f) Availability of information (studies, opinions, sectoral information, etc.); (g) Qualification of human resources; (h) Factors related to work organization; (i) Costs (acquisition, maintenance, etc.); (j) Indicators of market share, benchmarking, etc.; (k) Other financial indicators (accounting, Internal Return Rate, Net Asset Value, payback, etc.); and last (m) Other typology not described before.

5) The questionnaires asked about the use given to indicators in the decision of technology innovation. In this question respondents had to classify the intensity of the influence in a four-point Likert scale to force a choice identifying the agreement or disagreement with their use. In a closed question respondents had to totally disagree, disagree, agree or totally agree with the following seven statements: (a) Did indicators help to deal with the future (increased

competitiveness, scientific advances, technology development, etc.)?; (b) Did indicators help to understand the current situation?; (c) Did indicators help to characterize your policy/development/acquisition?; (d) Did indicators help to confirm your policy/development/acquisition?; (e) Did indicators help to justify your policy/development/acquisition decision (to the financing entity, politicians, management, colleagues, etc.)?; (f) Did indicators help to comply with formalities (with donors and national projects in Europe, the supervisory bodies, legislation, etc.)?; and last, (g) Were indicators unhelpful.

6) The questionnaires asked for a compulsory rating of the intensity of the influence of indicators. The rating was measured in a four-point Likert scale to force a choice between irrelevant, less important, important or very important to the decision. In this way respondents rated the influence in the decision of fourteen individuals/groups: Liable politicians/management/managers; Liable financier and accountants; Experts; Colleagues; Personal relationships (acquaintances, friends, etc.); Technology users; Salesmen/account managers/consultants; Business/industrial groups; (9) Researchers/academics; Other political decision makers; Consumers; Groups of citizens (associations, pressure groups, etc.); Society in general; and The media.

7) The questionnaires asked whether the indicators were more important than social relations to the technology innovation decision. In this closed question respondents had to answer yes or no.

8) The questionnaires asked compulsorily how the decision was perceived by the respondent regarding five topics: hierarchically; lonely; competitively; collaboratively; and with participation of other stakeholders. This closed question allowed responders to characterize their perceptions rating each as never, sometimes and many times. This three-point Likert scale was sufficient to measure the behaviour of the respondents in terms of their perceptions regarding the decision process (Lehmann and Hulbert 1972).

9) The questionnaires allowed the naming of other factors important to the technology decision. This was the only non-compulsory question common to the three questionnaires.

3.1.2 Standardized interviews

The survey also included standardized interviews, as mentioned previously. They are a data collection technique carried out in the presence of an interviewer to collect the same standardized data gathered in the self-administered questionnaires, and to allow room to develop other issues that could be relevant for the research (Leeuw 2008). In fact, the 26 face-to-face interviews were conducted not only to collect standardized data, but also to gather other information expressed in the interviews. Similar to the questionnaires, the interviews targeted researchers, business R&D&I leaders and policymakers, from February 2012 to June 2013. The majority of the interviews (13 interviews or 50%) targeted policymakers, followed by researchers (7 interviews or 27%) and the business community (6 interviews or 23%). The emphasis on interviews with policymakers was a way to collect responses, given the reluctance to respond to information considered sensitive by some respondents. Hence, confidential (and later anonymized) interviews provided ground to establish a trust relationship with the interviewees, which avoided their suspicion of misuse of information. The interviews lasted on average one hour. The interviews were important not only to collect the same information as the questionnaires, but also to give space for new issues to arise during the conversation and to reach saturation of information.

3.2 CASE STUDIES

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident (Simons 2009). The aim of practice-oriented case studies is not to prove whether a theoretical relation exists, but whether the hypotheses are "correct for the practice for which the study wants to be locally relevant" (Dul and Hak 2008, 220-221). In this case, the objective is to contribute to knowledge regarding the relevance of the context and the process of construction of evidence to understand the way indicators are used in decisions by the innovation groups (H5 and H6). An in-depth analysis of these processes can provide qualitative insights about actors' use of information in practice, how information is valued and the prevalence of formal scientific evidence use in policy decision.

The first case selected was a policy decision to build an electric mobility infrastructure across Portugal. In this work the decision was codenamed EMobi. The case of electric mobility is a frequent example of innovation in the S&T literature, and a preliminary examination detected the use of evidence in the media and other grey literature. The second case study was related to the creation of a nanotechnology laboratory. In this text, the decision was codenamed NanoLab. A preliminary scrutiny revealed a small number of decision makers, and a site geographically accessible in the north of Portugal. The selection of both cases also considered operational restrictions, such as the possibility to review documents and access to potential data and records, as well as the ability to contact and interview decision makers. Furthermore, these two cases involved complex decision process with the three main actors of technology innovation. Last, the case of electric mobility revealed that researchers were left out of the decision process. Thus, the selection of a second case study needed to guarantee (and complement) the in-depth study of all three groups, since it was a policy decision aimed mostly at the researchers group.

It should be noticed that the selection of policy cases strengthened the study of policy-making. There were four reasons for this focus: First, policy decisions were probably the most complex type of decisions identified. Second, the importance of the context and of the process of construction of evidence was more explicit in policy-making literature. Third, survey results revealed that the context and the process of construction of evidence were more emphasized by policymakers than by other groups. Fourth, policymakers were a difficult group to observe because they were less prone to answer surveys, needed substantial explanatory introduction to the research project and revealed the need for more secrecy. By coincidence, four policymakers were also involved in both case studies. Nevertheless, although this situation might restrain the number of actors in analysis, it also enriches the study of the use of evidence to decide, by presenting two examples where the same actors participated in different decisions.

In-depth interviews were conducted to answer open questions about the context of the decision and the process of construction of evidence. The interviews included the same guiding questions to analyse the context in relation to the political, economic and organizational environments, and the process of construction of evidence in relation to the way evidence and indicators were used. Thus, the first block included the following questions related to the context of the decision:

(1) “Please describe how the decision was made”,

(2) “Please describe the political context of the decision?”,

(3) “Please describe the economic context of the decision?”,

(4) “Please describe the difficulties and controversies faced during the decision”,

(5) “Please describe the different phases of the decision”,

(6) “Can you name those involved in the decision?”,

(7) “Please describe your role in the decision”,

(8) “Please describe the relationships between those involved in the decision”, and

(9) “Please describe other details related to the context of the decision that might occur to you”.

The second block of questions was related to the process of construction of evidence, and included the following questions:

(10) “Please describe the evidence and indicators used to make the decision”,

(11) “What was the purpose of those evidence and indicators?”,

(12) “Do you remember of any controversies related to those evidence and/or indicators?”,

(13) “Were the evidence and indicators collected before or after the decision?”, and

(14) “Please describe other details related to the use of evidence and/or indicators used to make the decision”.

The interviews were conducted to cope with the sensitive nature of the information requested, avoid any suspicion of misuse of information, and provide confidentiality to sources when that was possible. The first case study on electric mobility included 9 in-depth interviews to decision makers: 1

to researchers, 4 to business R&D&I leaders and 4 to policymakers. These interviews lasted from one hour up to four hours, and were conducted between February 2011 and March 2013. In the end, two complementary interviews were made to scholars with expertise on the case in March 2012 and in April 2013. Furthermore, the second case about the nanotechnology laboratory included 4 interviews with decision makers: 2 with researchers and 2 with policymakers. These interviews were conducted in March 2014 and lasted from one hour up to three hours. In the end, one complementary interview was made to a scholar in March 2014. In addition, the interviews created trust to talk with those linked with the decisions; enabled the collection of data until confidence and saturation of information was felt; and provided space for other questions to arise and to reveal insights. Some interviewees were asked to check the reports from their perspectives to ensure validation of information.

A social network analysis (SNA) was also developed for each case study. The SNA was conducted to complement the description of the organizational context of the decision, and to allow a comparative analysis of the measures found in the networks. It clarified the structure of the organizational context of the decision process with sociograms of the decision network (useful for understanding the actors' involvement and positioning in the network); the calculation of measures about the networks (useful in characterizing their cohesion, centrality, etc); and the identification of factions and core-periphery in the networks (useful for understanding the dynamics of the process of decision-making). Furthermore, the questions raised in the interviews enabled extensive actor identification to apply SNA in case studies. Questions 6, 7, 8 and 9 were intended to gather data for the construction of SNA in both cases. The socio-matrixes describing the relationships within the network are presented in Table 7.1 for EMobi and in Table 7.2 for NanoLab in Annex 3 – Supplementary tables. The identification of actors was developed during interviews through snowballing until full network saturation was achieved (see Morgan 2008). This method provided access to "hidden" populations of decision makers and, at the same time, avoided sampling bias. Furthermore, the information presented in the case studies allowed the use of various established methods for constructing sociograms of the decision (presented in Figure 4.2 and Figure 4.3); to calculate metrics characterizing the networks and individual actors (the logs are presented in Annex 4 – Ucinet files); to recognize subgroups in the network such as factions; and to identify the equivalence patterns in these social networks using core-periphery models. These sociograms and measures were calculated using Ucinet 6 for Windows Version 6.528.[85] The figures were plotted using Netdraw Version 2.141.[86] The factions and core-periphery figures were not considered essential to describe the social networks, and were presented in Annex 2 – Supplementary figures (Figure 7.1, Figure 7.2, Figure 7.3 and Figure 7.4).

[85] Borgatti, Everett, and Freeman (2002) Ucinet 6 for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.
[86] Borgatti, Everett, and Freeman (2002) Netdraw Network Visualization. Analytic Technologies: Harvard, MA.

The literature indicates that there is often a methodological issue in SNA, which should be addressed from the start. The point relates to the criteria defining the relationships in a social network. In fact, the researcher makes these definitions in an analytical selection procedure. The selection is based on the choices of the set of nodes and the types of ties established through empirical data collected in the interviews of the case study (Marin and Wellman 2011; Borgatti and Halgin 2011). The choices comprise the initial elements determining the influence between decision makers in the two cases studies. According to Borgatti and Halgin (2011), there is often an inaccurate concern that researchers may select nodes "incorrectly", thereby possibly accidentally excluding important nodes and including other less relevant relations. However, the authors argued that, in reality, the choice of nodes should not be regarded as an empirical question, because those choices are dictated by the research question and explanatory theory. Furthermore, unlike a group, networks do not have "natural" boundaries, neither do they have to be connected (Borgatti and Halgin 2011), which allows for a better fit with the research questions.

3.3 COMPLEMENTARY INTERVIEWS

Last, the research also included complementary interviews to discuss the findings with known specialists and answer remaining questions resulting from the previous work. The interviews were in-depth, during which individual respondents were questioned at length about a particular issue and their own experience. This work included four complementary interviews conducted with researchers who were renowned experts in the field of indicators and technology innovation located in Portugal, Germany and the United Kingdom, during April 2012 to June 2014.

4. RESULTS

This chapter presents results that answer the three research questions mentioned in Chapter 2. The first subchapter provides results on determining the extent of the influence of indicators in decisions of technology innovation. The next provides results on determining the role of indicators in these decisions. The last subchapter presents results concerning the way indicators were involved in these decision-making processes.

4.1 WHAT IS THE INFLUENCE OF INDICATORS?

This sub-subchapter addresses the extent of the influence of indicators in decisions of technology innovation. As mentioned previously, there are no records of quantitative information about the use and influence of indicators in the technology innovation literature. Therefore, results presented here focused on the quantification of the major characteristics associated with the use and influence of indicators by surveying individuals directly involved in decisions of technology innovation. This effort allows for the ascertaining of the initial background information necessary to understand indicators' reach in practice. The following section presents results concerning the use of indicators in these decisions by innovation groups. The second section addresses the influence of indicators in these decisions.

4.1.1 Use

The use of indicators provides information about the extent of their use during a significant decision of technology innovation. The following table summarizes the answers and percentages obtained in the survey by the innovation group.

Table 4.1 – Number and percentage of answers to the question "Did you use indicators during a technology decision?" by group

	Yes		No		Total	
	Answers	%	Answers	%	Answers	%
Researchers	22	71%	9	29%	31	100%
Business R&D&I	32	89%	4	11%	36	100%
Policy makers	22	92%	2	8%	24	100%
All groups	76	84%	15	16%	91	100%

Table 4.1 reveals a clear pattern of use of indicators during decisions of technology innovation. In fact, the vast majority (84%) of all answers revealed that indicators were used during these decisions. Only 16% of the respondents said that they did not use them. Furthermore, a closer look into the three groups under observation revealed differences: the vast majority of policymakers (92%) revealed they used indicators in their decisions; 89% of the business R&D&I leaders answered that they used indicators to decide; and 71% of researchers answered that they used indicators during their decision.

In sum, the extent of the use of indicators in these decisions is significantly high, although slightly differentiated in each group: the vast majority of policymakers use indicators, followed closely by business R&D&I leaders and soon after by researchers. The measures to prevent bias in results were described in Chapter 3.

4.1.2 Influence

The intensive use of indicators might not necessarily mean that they were influential in the decision, as mentioned in Chapter 2. Therefore, it is important to distinguish the use of indicators from the real influence of indicators in these decisions. The following table presents results from the survey on the influence of indicators.

Table 4.2 – Number and percentage of answers to the question “Do you think that indicators were more influential than social relations during the technology decision?” by group

	Yes		No		Total	
	Answers	%	Answers	%	Answers	%
Researchers	11	50%	11	50%	22	100%
Business R&D&I	13	41%	19	59%	32	100%
Policy makers	7	32%	15	68%	22	100%
All groups	31	41%	45	59%	76	100%

Table 4.2 reveals three main features: First, indicators were more important than social relations to the majority (59%) of all respondents involved in these decisions. Second, the majority of both policymakers and the business group (68% and 59% respectively) answered that social relations were more important than the use of indicators. Third, the answers of the researchers were even (50%), which suggests that indicators can be as important as social relations in the decision process. In sum, social relations were more important than indicators to policymakers and business R&D&I leaders, but as important for researchers.

There is a gap between the use and influence of indicators in these decisions. The following table compares results from the survey about the use and influence of indicators in decisions by group.

Table 4.3 – The use and influence of indicators in decisions by group

	Did you use any indicators in your decision?			Were indicators more important than other individuals/groups?		
	Yes	%	Total	Yes	%	Total
Researchers	22	71%	31	11	50%	22
Business R&D&I	32	89%	36	13	41%	32
Policy makers	22	92%	24	7	32%	22
All groups	76	84%	91	31	41%	76

Table 4.3 reveals that the more indicators were claimed to have been used, the less influential they were in technology innovation decisions. In fact, in comparison, more policymakers claimed to use indicators (92%) and to be less influenced by them (32%); business R&D&I leaders slightly less often used indicators (89%) and were slightly more influenced by them (41%); and researchers tend to use indicators less (71%) but were more influenced by them (50%). Therefore, the gap between use and influence is larger for policymakers (92% and 32%); it decreases for business R&D&I leaders (89% and 41%); and is smaller for researchers (71% and 50%). These different gaps suggest a different decision process for each group.

Results showed that social relations can significantly influence decisions of technology innovation, hence the need to identify in detail the origin of these social influences. The following table presents results from the survey relating to the most important influences of decisions by group.[87]

Table 4.4 – The most important influences in the decisions by group

	Researchers		Business R&D&I		Policy makers		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Management / Managers / Politicians	7	23%	25	69%	15	63%	47	52%
Financial directors and accounters	5	16%	4	11%	4	17%	13	14%
Experts	16	52%	11	31%	7	29%	34	37%
Colleagues	11	35%	9	25%	3	13%	23	25%
Personal relationships (acquaintances, friends, etc.)	4	13%	2	6%	3	13%	9	10%
Technology users	13	42%	14	39%	4	17%	31	34%
Salesmen/Account managers/Consultants	0	0%	3	8%	0	0%	3	3%
Business / Industrial groups	4	13%	4	11%	4	17%	12	13%
Researchers / Academics	13	42%	4	11%	3	13%	20	22%
Other political decisors	0	0%	2	6%	3	13%	5	5%
Consumers	4	13%	15	42%	4	17%	23	25%
Groups of citizens (associations, pressure groups, etc.)	1	3%	1	3%	3	13%	5	5%
Society in general	2	6%	0	0%	2	8%	4	4%
Media	1	3%	0	0%	1	4%	2	2%
Other	0	0%	0	0%	0	0%	0	0%
Total	*31*	*100%*	*36*	*100%*	*24*	*100%*	*91*	*100%*

Table 4.4 reveals different influences in each innovation group. First, researchers indicated that *experts* were the most important influence on their decisions (52%), followed by *technology users* and *researchers/academics* (ex aequo 42%). These responses suggest significant relevance of knowledge sources and users in the decisions of this group. Second, the business R&D&I leaders indicated that *managers* (69%) were their most important influence, followed by *consumers* (42%). These answers

[87] Only results classified as "Very important" are shown in the table.

suggest that hierarchies and users were the main influence in this group. Third, policymakers indicated that *politicians* (63%) and, to a lesser extent, experts (29%) were their most important influences. These answers suggest that hierarchies and knowledge sources were the main influences in this group. The following figure summarizes these results aggregating the type of influence during the technology innovation decisions.

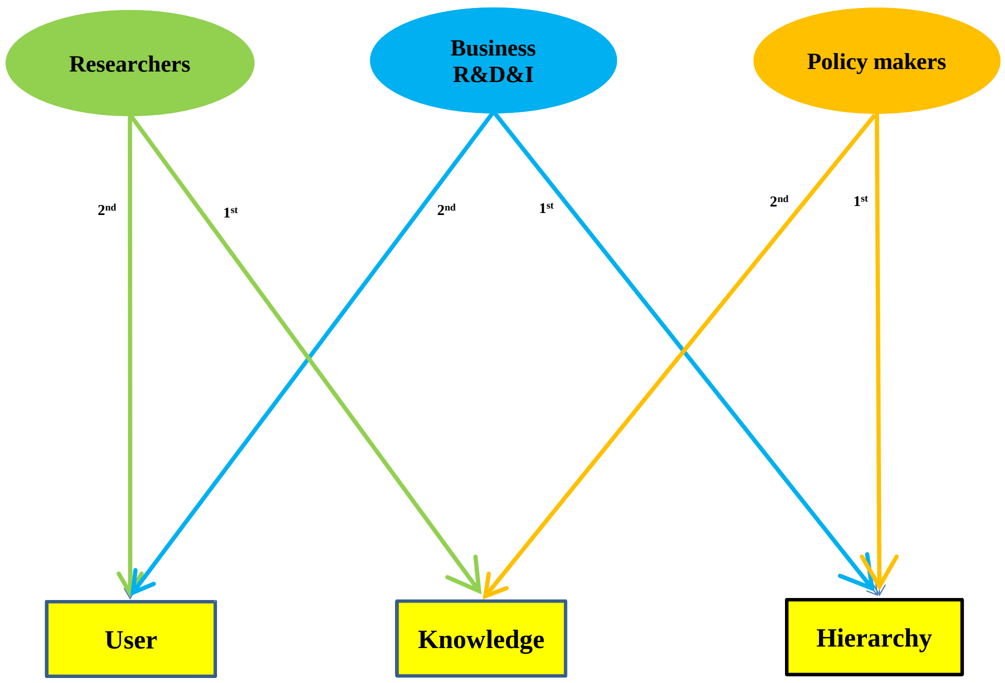


Figure 4.1 – The most relevant types of influences in the decisions by group

Figure 4.1 reveals that groups are significantly influenced by hierarchies, knowledge sources and users. First, the hierarchies were the most relevant influence on the decisions of business R&D&I leaders and policymakers. In fact, these two groups declared *managers* and *politicians* to be the most relevant influence in their technology decisions (1st choices). Second, knowledge sources were also a significant influence on decisions. In fact, not only did researchers reveal that *experts* and *researchers/academics* were one of the most significant influences to their decisions, but policymakers also indicated that *experts* were significantly influential (2nd choice). Third, users of the technology were also a significant type of influence in these decisions. In fact, both researchers and business R&D&I leaders indicated *users* as a relevant influence in their decisions (ex aequo 2nd choice). In sum, results revealed that the most important influences in technology innovation decisions came from hierarchies, knowledge sources and users of technology, although as a different combination for each group.

To conclude, Hypothesis 1 was confirmed: Despite their high level of use, indicators have low influence on decisions of technology innovation made by the three innovation groups.

4.2 WHAT IS THE ROLE OF INDICATORS?

This sub-section presents results concerning the role of indicators based on the questionnaires and supplemented with results from the interviews. Chapter 2 defined three categories for understanding the role of indicators: instrumental, symbolic and no role. The following table presents results from the survey related to the role of indicators by group.

Table 4.5 – The role of indicators in decisions of technology innovation by group

	Instrumental		Symbolic		No role		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Researchers	11	35%	11	35%	9	29%	31	100%
Business R&D&I	13	36%	19	53%	4	11%	36	100%
Policy makers	7	29%	15	63%	2	8%	24	100%
All groups	31	34%	45	49%	15	16%	91	100%

Table 4.5 reveals different features generally and at the group level. Overall, the table presents a heterogeneous pattern for all groups with three main features: indicators played mostly a symbolic role in all decisions (49%); a smaller portion of all decisions used indicators instrumentally (34%); and only 16% of all answers revealed no role at all. Furthermore, at the group level the table reveals four main ideas: First, indicators were symbolic to the majority of policymakers and business R&D&I leaders (63% and 53%, respectively). Second, indicators were instrumental to circa one third of decisions in the three groups (i.e. varying in the interval [29% to 36%]). Third, results for researchers were distributed evenly between instrumental and symbolic (each 35%). Fourth and last, only a few revealed that indicators had no role in the decision, although the percentage was higher for researchers (29%). In short, the role of indicators was mostly symbolic, they were instrumental to approximately a third of the decisions, and policymakers and business R&D&I tend to use indicators symbolically more often than researchers.

The interviews can also complement these results with findings regarding the role of indicators in these decisions:

– Interviews with researchers can help to explain the pattern of relative significance of indicators found in the survey when compared to the other two groups. In fact, two researchers revealed an instrumental use of indicators, another symbolic: one researcher pointed out that her decision to buy an expensive jet printer to create biosensors in the laboratory involved previous discussions with her colleagues, instrumentally centred on the cost of acquisition (I6[88]); another researcher

[88] References to information collected through interviews are hereafter made using an acronym and a number to maintain both anonymity and internal control. As described previously, the acronym PI indicates Preliminary

revealed an instrumental use of indicators related to technology characteristics and to the qualification of human resources in his acquisition of electro-technical software (I8); and yet another researcher revealed that his decision to develop technology was symbolically based on indicators related to technology characteristics, suppliers and qualification of human resources (I5). In sum, results from researchers interviewed also confirm that indicators can have an instrumental and symbolic role in their decisions.

Indicators can be highly valued by researchers in fields related to innovation studies and technology assessment. In fact, in an interview with a researcher[89] the contextualised use of indicators is helpful to conduct a reasonable interpretation of data and to balance options (PI6). To this interviewee, using indicators implies dealing with what is possible to measure, which is a limited perception of reality with restricted reliability (PI6). The researcher also considered not being free from abuse or misinterpretation of data, and argued that these problems can arise from other types of research as well (PI6). Furthermore, two academics argued that indicators capture only a parcel of reality because a substantial part of reality can be left out of any indicators analysis (CI1 and CI2). This idea corresponds with the potential for deception in the use of indicators mentioned in subchapter 2.1.

– Interviews with business R&D&I leaders can help explain the pattern of decision-making found in the survey, described as similar although less intense than the pattern of policymakers. In fact, among the interviewed business R&D&I leaders who had made the same type of decisions (development of product/technology), the influence of indicators varied, from symbolic in three cases to instrumental in another. One interviewee working for a large oil company, which considered indicators to be mostly symbolic in the decision process, described the influence of indicators as follows:

> Obviously, we use indicators. But, in the end, all companies have the same numbers. And economic models depend too much on our assumptions. […] Either [the CEO[90]] believes [in the new product] or not, even if we put all those numbers. Numbers can be fantastic but if [the CEO] doesn't believe in [the product], it will not be developed. (I22, lines 408-409 and lines 423-424)

According to this interviewee, decisions are dependent on her preliminary judgment of the potential benefits of a product in terms of its competitiveness in the market (I22). The decision also depends on the ability to convince/influence the CEO of the company that the product will

Interview, I designates Interview and CI specifies Complementary Interview. The number that follows these acronyms indicates the number of the interview. Direct quotations will also include a reference to the line numbers where the quotation can be found in the transcription document.

[89] The interviewee was a senior German researcher of one reputed research institute delivering innovation policy services.

[90] CEO is the acronym of Chief Executive Officer.

sell (I22). The interviewee later conceded that, to some extent, political and market-share pressures (i.e. the political and economic context) can determine participation in some innovation projects (I22). Furthermore, in three small and medium companies, the opinion of their clients was also described as important to the final decision (PI11, I3 and I4). According to one interviewee from a medium-sized consultancy company, some technology decisions resulted from managers' own interests and agendas rather than any objective criteria (PI11).

These variations in the role of indicators in business R&D&I leaders' decisions may not be so much related to sector differences or to the size of the company, but more to the culture of the firm, according to the interviewees. First, the sector of performance does not appear to be significant to understand the role of indicators. For example, one interviewee working with healthcare clinics described indicators as symbolic (PI11), whereas another interviewee working also with healthcare clinics considered indicators instrumental to the decision (I4). In addition, interviews suggest that the sector of activity might not be so significant to the role of indicators. For example, three interviewees in companies working in technology applications, consultancy and oil sectors described the influence of indicators as symbolic (PI9, I3 and I22), and one in an open-source software company revealed that the influence of indicators was instrumental (I3). Second, the size of the company does not appear to be significantly determinant to the role of indicators in decisions by business R&D&I leaders. For example, two interviewees in medium companies and two in a large firm described the influence of indicators as symbolic (PI11, I3, I19 and I22); and one in a small company revealed that the influence of indicators was instrumental (I3). In all these cases, however, interviewees significantly highlighted that the culture of the company had some influence over the role of indicators in the decisions. Some even complained about the difficulties to persuade managers and other decision makers in Portuguese companies (PI11, I3, I19 and I22).

– Interviews with policymakers may help explain the major symbolic role of indicators detected in the survey. As mentioned previously, two case studies will be presented in the next section to deepen the understanding of context and process of construction of evidence in policy decisions. Nevertheless, experts revealed five main ideas about policy-making that warrant mentioning, separate from the case studies:

1. Results from the survey suggest that innovation indicators play a limited role in policy-making. In fact, indicators were even considered irrelevant to decision-making in an interview to a Swiss senior innovation policymaker (PI5). The interviewee stated that indicators are used to confirm that "we are in an excellent position" (PI5, line 543), an idea partially corroborated by two Swiss governmental officials working in the Ministry of Science (PI4). This limited role is in line with the literature. In fact, a study about sustainability indicators presented similar findings about the symbolic use of indicators (Gudmundsson and Sørensen 2012), as

described in Chapter 2. Therefore, there is meagre evidence of an important role for indicators in innovation policy.

2. Results from the interviews with experts and policymakers suggest that the role of indicators and, more generally, of evidence varies substantially. In fact, according to some interviewees most policy studies were driven by (i) curiosity during the decision, (ii) need for subsequent legitimisation of decisions, and (iii) obligation (from administrators and bureaucrats, particularly officials of the EU, ministers, etc.) (PI4, PI5, PI6, I10, I21, I22, I26 and CI3). According to some researchers, the first and second purposes for requesting a policy study stems from the need to communicate their decisions and formulate press releases (PI5 and PI6), to advocate a policy position (PI6), to increase visibility for policy purposes (PI6 and PI9) and to favour personal agendas (PI6, PI11, PI5 and I25). These findings are in line with the argument of Lehtonen (2013), that scientific knowledge for sustainability (including evaluations, assessments and indicators) seldom plays an instrumental role in policy-making, and is more likely to produce indirect, conceptual and political effects. However, intent to manipulate can be found regarding indicators and evidence when soliciting policy studies to advocate a particular policy position, increase visibility and favour personal agendas (PI6). These behaviours can be framed within the context of forces of social regulation and social integration limiting actors' behaviour, as mentioned in Chapter 2. Furthermore, the third reason to request a policy study (for the sake of self-preservation of bureaucracy) can also be framed in the same context. In these cases, studies are requested to show that policy managers do something and thus legitimise their existence, according to one researcher (PI6). For example, more frequently than at the national level, EU policymakers request studies "to throw away without any reflection on the content, because bureaucratic administrators intend to keep on doing the same thing", stated a researcher (PI6, line 29-30). Nevertheless, the majority of interviewees agreed that most politicians demanding studies are moved by curiosity and their need to monitor their systems (PI3, PI4, PI6, PI12, I11, I14, CI3 and CI4). In fact, most policymakers still expect a solid study with a reasonable scientific approach to the question, although they are not interested in the technical issues of studies (PI6, line 75-77).
3. An English researcher[91] of policy indicators stated that policymakers increasingly use indicators to decide and are more aware of their dangers (CI4). However, the interviewee admitted that the expert community responsible for the production and analysis of STI indicators was not always sufficiently clear about abuses in the use of indicators. Furthermore, the researcher suggested, "there might be some countries where things are going wrong" (CI4, line 80-81). Nevertheless, the interviewee mentioned that at least in publications and evaluations based on indicators in the United Kingdom and Germany, policymakers are aware

[91] The interviewee was an English senior academic with an expertise in policy indicators for evaluation.

of limitations and generally avoid relying heavily on particular indicators (CI4). For example, policymakers in these countries expect research funding agencies and their reviewers to analyse “the proposal rather than counting the publications and citations mentioned in the proposal” (CI4).

4. Seven policymakers and experts agreed upon the sensitive nature of selecting indicators in innovation policy studies (PI6, PI9, I11, CI1 and CI4). According to the interviewees, the decision to use one indicator instead of another is significantly relevant to policy-making (PI6, PI9, I11, I12, I15, CI1 and CI4). Three interviewees argued that choosing one group of indicators and leaving others aside could capture a single-sided view of a more complex reality (PI6, CI1 and CI4). These sometimes controversial decisions need to be transparent and as consensual as possible among actors, stakeholders and in society to reduce room for randomness when choosing parts of a complex reality, according to two researchers and one policymaker (PI6, I11 and CI1). The solution is to measure what is possible while knowing the limits of indicators, and present what is conceivable given those limits, according to one researcher[92] and a policymaker (PI6 and I11).
5. There is also the risk of oversimplification, particularly in policy-making, when dealing with innovation indicators, as mentioned in Chapter 2. In fact, a researcher in innovation policy studies asserted that the policy communication process played an important role in his research-oriented work. He revealed that policymakers often required him to present “two pages and strong statements” (PI6, line 348). Two researchers sustained that composite indicators (or indexes) can be used to present a case, because they were useful and helped deliver a message when interpreted and used in the right context (PI3 and PI4). The expert researcher in innovation policy studies added that it was possible to find causality and some coherence in studies using innovation composite indicators (PI6). This perspective is in line with some findings in the literature where policymakers consider composite indicators useful to their work, as mentioned in Chapter 2 (see among others Nardo et al. 2008; Saltelli 2007; Sébastien and Bauler 2013). Other interviewees, however, were cautious about the use of these composite indicators (PI2, PI4 and PI9). This is in line with some literature as well. In fact, some authors have doubts about composite indicators alerting to misuses and methodological problems (Grupp and Schubert 2010). It can be argued, therefore, that more studies on the limits of composite indicators are needed, given the diversity of results found.

To conclude, Hypothesis 2 was confirmed for business R&D&I leaders and policymakers, where indicators have mostly a symbolic role in their decisions. However, hypothesis 2 was not confirmed for researchers, where indicators can either play an instrumental, symbolic or no role in their decisions.

[92] The interviewee was a senior German researcher of one reputed research institute delivering innovation policy services.

4.3 HOW ARE INDICATORS USED?

This subchapter presents results to understand how indicators are involved in the decision-making process of technology innovation. The subchapter is divided in three sections addressing the possible explanatory factors: type of decision, phase of decision, and context and process of construction of evidence.

4.3.1 Type of decision

As discussed in chapter 2, the type of decision can be an explanatory factor to understand the way indicators are used in decisions of technology innovation. The relevance of the type of decision was primarily captured in eight interviews. Researchers with specific expertise in the field confirmed that each type of decision requires indicators in different ways (PI6, PI7, I7, I11, CI1, CI2, CI3 and CI4).

Furthermore, the survey captured the relevance of this factor. The following table presents results related to the type of decision for those who used indicators.

Table 4.6 – Number and percentage of answers to the question "Do you consider indicators more influential to the decision than social relations?" by type of decision

	Yes		No		Total	
	Answers	%	Answers	%	Answers	%
Acquisition of equipment/technology	15	48%	16	52%	31	100%
Development of products/technology	10	42%	14	58%	24	100%
Policy design	6	30%	14	70%	20	100%
Total	31	41%	45	59%	76	100%

Table 4.6 reveals that the influence of indicators varies with the type of decision. In fact, the percentage of those who considered indicators more important than social relations varied with the type of decision: 48% for decisions of acquisition of equipment/technology; 42% for development of product/technology and 30% for policy design. The data about property rights is not sufficient for analysis.

In addition, the survey allows categorization of the role of indicators by type of decision. The following table presents results from the survey related to the role of indicators by type of decisions.

Table 4.7 – The role of indicators by type of decisions

	Instrumental		Symbolic		No role		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Aquisition of equipment/technology	15	38%	16	41%	8	21%	39	43%
Development of products/technology	10	34%	14	48%	5	17%	29	32%
Policy design	6	29%	14	67%	1	5%	21	23%
Total	31	34%	45	49%	15	16%	91	100%

Table 4.7 reveals that the role of indicators was symbolic to a vast majority of policy decisions (67%), but less emphatically in decisions of development of product/technology (48%) and acquisition of

equipment/technology (41%). Furthermore, there is a heterogeneous pattern of roles in acquisition of equipment/technology and development of product/technology (respectively 38%, 41% and 21%; and 34%, 48% and 17%). By contrast, findings revealed a more defined pattern for the role of indicators in policy-making (respectively 67%, 34% and 16%). The data about property rights is not sufficient for analysis. These differences suggest that the type of decision is important to explain how indicators are involved in the decisions.

The type of decision might also influence the indicators involved in the decision process. The following table presents results about the most relevant types of indicators to respondents by type of decision.[93]

Table 4.8 – Answers and percentages of responses to the question "Please select three types of indicators most relevant to your decision" by type of decision

	Acquistion of equipment/technology		Development of products/technology		Policy design		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Use of technology by partners	11	13%	7	15%	0	0%	18	10%
Use of technology by competition	3	4%	1	2%	0	0%	4	2%
Suppliers (easy relationship, their characteristics, their type, etc.)	6	7%	4	9%	0	0%	10	6%
Technical characteristics of the technology	26	31%	11	23%	10	32%	63	35%
Availability of information (studies, opinions, sectoral information, etc.)	6	7%	4	9%	5	16%	15	8%
Qualification of human resources (internal)	3	4%	4	9%	1	3%	8	4%
Factors related to work organization	1	1%	2	4%	0	0%	3	2%
Costs (acquisition, maintenance, etc.).	16	19%	11	23%	13	42%	40	22%
Indicators of market share, benchmarking, etc.	6	7%	1	2%	0	0%	7	4%
Other financial indicators (accounting, IRR, VLA, Payback, etc.)	6	7%	2	4%	2	6%	10	6%
Others: Please name them	0	0%	0	0%	0	0%	0	0%
Total	84	100%	47	100%	31	100%	178	100%

Table 4.8 reveals four main features about the type of indicators per type of decision: First, the most significant type of indicators in decisions of acquisition of equipment/technology were technical characteristics of technology (31%), followed by costs (19%), and, to a lesser extent, by indicators of the use of technology by partners (13%). Second, the most significant type of indicators in decisions of development of product/technology were both technical characteristics of technology (23%) and costs (23%), followed by indicators of the use of technology by partners (15%). Third, in a different way, the most significant type of indicator in decisions of policy design was costs (42%), followed by technical characteristics of technology (32%) and, to a lesser extent, availability of information (16%). Fourth and last, other types of indicators were not significantly used, such as indicators of competition,

[93] In the survey, the respondents were asked to select the three most important typologies of indicators used in the decision among those identified or to indicate another category. Policymakers had an open question without any restrictions.

suppliers, qualification of human resources, factors related to work organization, indicators of market share and benchmarking, and other financial indicators (accounting, Internal Rate of Return, Net Present Value, payback, etc.). Other types of indicators were not mentioned. The data about property rights is not sufficient for analysis. In sum, the most mentioned types of indicators in decisions of acquisition of equipment/technology were the technical characteristics of technology; in decisions of development of product/technology were both characteristics of technology and costs; and in decisions of policy design were costs.[94]

Furthermore, the interviews revealed more diversified types of indicators. In fact:

- The interviews about decisions of acquisition of equipment/technology revealed diverse types of indicators, with an emphasis on the use of technical characteristics of the technology. For example, a researcher reported emphatically the indicator of cost and, to a smaller extent, indicators of technology characteristics (I6); another interviewee, who had acquired software, identified the use of indicators of technology characteristics and qualification of human resources (I8).
- The interviews about decisions of development of product/technology also revealed diverse types of indicators. In fact, two decisions (one by a researcher and another by a business R&D&I leader) revealed the use of indicators of technical characteristics of technology, combined with indicators of technology used by partners and qualification of human resources (I3 and I5). In a slightly different way, another interviewee selected other types of indicators. In fact, this interviewee from a small company based on the development of open-source software used indicators related to technology used by partners, suppliers and availability of information (I4).
- The interviews about policy decisions primarily emphasized the technical characteristics of their policies (I9, I10, I11, I14, I15, I16, I17, I21 and I26), and the financial cost (I1, I10, I13, I14, I16, I25 and I26). Four policymakers also identified indicators related to the availability of information (I11, I12, I14, I15 and I25). It should be noted that some of these interviews suggested that the position of the decision maker in the policy process was important to describing the role of indicators: those involved with the preparation of policies emphasized technical characteristics (I9, I16, I17, I21 and I26); parliamentarians emphasized the availability of information (I11, I12, I14 and I15); and those leading negotiations emphasized costs (I25 and I26).

In sum, the interviews about decisions of acquisition of equipment/technology and development of product/technology revealed diverse types of indicators. Interviews about policy decisions revealed an emphasis on indicators of technology characteristics and costs, and suggested that the position in the policy process was important to understanding the role of indicators.

[94] The Table 7.1, in the Annex 3 – Supplementary tables, complements these results with data about the purpose of indicators by type of decision.

To conclude, results suggested that Hypothesis 3 is confirmed: The type of decision helps to explain how indicators are used in decisions of technology innovation. First, interviewees confirmed that each type of decision requires indicators in different ways. Second, surveys showed heterogeneous patterns of roles (between instrumental, symbolic and no role) in acquisition of equipment/technology and development of product/technology; by contrast, policy-making highlighted the symbolic role. Third and last, survey results revealed that the most used types of indicators are different in each decision: in decisions of acquisition of equipment/technology were technical characteristics of technology; the most used types of indicators in decisions of development of product/technology were both characteristics of technology and costs; and in decisions of policy design were costs. Interviews showed more diversified type of indicators.

4.3.2 Phase of decision

Results suggest that the phase of decision is an explanatory factor in understanding how indicators were involved in the decisions. In fact, most interviewees confirmed this idea by providing details of their experience. First, seven interviewees stated explicitly that the phase of the decision process influences the role of indicators at least before and after the decision (PI7, I7 and I11, CI1, CI2, CI3 and CI4). Second, other interviewees corroborated the existence of these and other phases in the decision process with different intensity of use of indicators:

- Interviews with those involved in acquisitions of equipment/technology indicated use of indicators often before the decision. Two interviewees agreed about the need to use them to make a final decision in discussions with their colleagues (I6 and I8). For example, a researcher pointed out that her decision to buy an expensive jet printer to create biosensors involved previous discussions about the benefits and negotiations with her colleagues based on an indicator of the financial cost (I6). Furthermore, these two interviewees revealed no use of indicators after the decision (I6 and I8).
- Interviews with those involved in decisions of development of product/technology described four possible phases in the decision process: First, the interviewees agreed they were responsible for the preliminary judgment on potential benefits of a new product/technology (PI11, I3, I4, I5 and I22). Second, they described activities to collect indicators and other evidence as well as specific analyses to support the decision (PI11, I3, I4, I5 and I22). For example, a business interviewee solicited an analytical study from a think-tank previous to the final decision (I22). In another case, a researcher revealed that the need to seize a scientific opportunity led to an ad hoc collection of indicators (I5). Third, four interviewees described the use of political-behavioural methods such as discussion, networking, negotiations and/or consensus-building activities in the decision process (PI11, I3, I4 and I22). For example, an interviewee conceded that to some extent political pressures can determine the development of products through negotiations and networking activities (I22). Fourth, five interviewees considered the CEO to be responsible for the final decision about the implementation of a new product/technology (PI11, I3, I4 and I22). In one case, the interviewee in a large oil company disclosed that the final technology decision largely depended on the CEO’s decision (I22). Others interviews revealed that the final decision was dependent on the client (PI11 and I4). In sum, those involved in development of product/technology described four different moments of the decision process: an initial phase where they made a preliminary judgment, followed by a rational-analytical collection of information, a political-behavioural activity and a final decision that may include negotiations and networking.
- Interviews of those involved in policy-making also identified four possible phases in their decisions. In fact, thirteen interviewees described the policy process of technology innovation as

having distinct phases (I1, I9, I10, I11, I12, I13, I14, I15, I16, I17, I21, I25 and I26): First, five interviewees described their involvement in the preliminary judgment of the potential political benefits of the policy (I11, I12, I14, I17 and I25). Second, six policymakers were revealed to be part of the political-behavioural approaches used to make a policy decision such as discussions, negotiations, networking, compromises and consensus-building (I9, I10, I13, I15, I16 and I26). Another policymaker also disclosed the use of negotiations after a final decision (I25). Third, twelve interviewees were involved in rational-analytical activities such as collecting indicators, and other evidence and analysis to support policy-making (I1, I9, I10, I11, I12, I13, I14, I15, I16, I17, I21 and I26). One policymaker mentioned that the indicator of the average number of students per class was often used before a decision, and seldom afterwards (I11). In another example, an academic and a policymaker both involved in innovation policy emphasized that indicators can be used in the policy process either before or after the final decision (I7 and I11). Fourth and last, three interviews with policymakers revealed they were directly involved in making the final decision (I11, I12 and I15). Results, then, show that the policy process includes at least a preliminary judgment of benefits and a final decision, although sometimes they can also include political-behavioural approaches and rational-analytical methods before and after the decision.

Other results captured the relevance of the phase of a decision in explaining how indicators are used in these decisions. The following table presents results from the survey about the intensity of use of indicators before the decision when indicators were considered more relevant than social relations.

Table 4.9 – Number and percentage of answers that agreed that indicators were more influential than social relations before and after the decision

	Never		Sometimes		Often		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Before	0	0%	6	19%	25	81%	31	100%
After	14	45%	7	23%	10	32%	31	100%

Table 4.9 first reveals an intensive pattern of influential use of indicators before the decision. In fact, the vast majority (81%) of respondents revealed the influential use of indicators *often before* making a decision. Only 19% used indicators *sometimes before* the decision. Furthermore, the table reveals a degree of heterogeneity in *after* a decision was made. In fact, the majority (45%) revealed *no use* of indicators after the decision, followed by 32% that used them *often*, and by 23% who used them *sometimes after* making a decision. These different patterns confirm the existence of two different phases of the decision process: the influential use of indicators was significant *before* the decision and heterogeneous *after* the decision.

An analysis by type of decision also confirms different intensities in the use of indicators in the two different phases of the decision. The following table presents results from the survey about the intensity of use of indicators before making the decision by type of decision.

Table 4.10 – Number and percentage of intensity in the use of indicators before decision by type of decision

	Before the decision							
	Never		Sometimes		Often		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Acquistion of equipment/technology	0	0%	4	13%	27	87%	31	100%
Development of products/technology	0	0%	3	13%	21	88%	24	100%
Policy design	0	0%	6	30%	14	70%	20	100%
Total	0	0%	13	17%	63	83%	76	100%

Table 4.10 reveals an intensive pattern of use of indicators before the decision. In fact, the vast majority (83%) of all respondents used indicators *often before* making a decision. Results were higher among development of product/technology (88%) and acquisition of equipment/technology (87%), and high but less expressive in policy design (70%). The data about property rights is not sufficient for analysis. In sum, all respondents used indicators *often before* the decision, although less so in policy decisions.

Furthermore, the following table presents results from the survey about the distribution of intensity of use given to indicators after a decision by type.

Table 4.11 – Number and percentage of the intensity of the use of indicators after decision by type of decision

	After the decision							
	Never		Sometimes		Often		Total	
	Answers	%	Answers	%	Answers	%	Answers	%
Acquistion of equipment/technology	18	58%	11	35%	2	6%	31	100%
Development of products/technology	6	25%	9	38%	9	38%	24	100%
Policy design	7	35%	7	35%	6	30%	20	100%
Total	32	42%	27	36%	17	22%	76	100%

Table 4.11 reveals one homogenous pattern and two heterogeneous patterns after a decision was made. First, decisions of acquisition of equipment/technology presented a homogenous pattern, where a majority of 58% admitted to never using indicators, 35% used indicators sometimes, and only 6% indicated having used them often. Second, there were two heterogeneous patterns among decisions of policy design and development of product/technology. In these two types of decisions, 35% and 25% respectively admitted never using indicators after the decision, 35% and 38% claimed to have used indicators sometimes, and 30% and 38% acknowledge using them often. The data about property rights is not sufficient for analysis. In short, the intensity of the use after the decision was homogenous for acquisition of equipment/technology and heterogeneous for decisions of policy design and development of product/technology.

Conclusively, the use of indicators before making a decision was intensive in all types of decisions, although less expressive in policy design. After the decision, there was one homogenous pattern in acquisitions of equipment/technology and two heterogeneous patterns among policy design and development of product/technology. Therefore, results by type of decision showed different patterns before and after the decision. These patterns of use confirmed the existence of different phases in the decision process.

To conclude, results confirm Hypothesis 4: the phase of decision helps to explain how indicators are used in decisions of technology innovation. Interviews confirmed two important moments - before and after the decision – with a preliminary evaluation of the potential benefits of the decision in terms of knowledge, competitiveness or political assessments. These processes can include political-behavioural methods before and/or after the final decision, such as discussion, negotiation, networking, consensus-building and/or other social activities. The decision processes can also involve rational-analytical activities before and/or after the final decision, such as collection of indicators, other evidence and/or other analyses. Furthermore, the use of indicators before making a decision was intensive in all types of decision, although less expressive in policy design. After the decision, there was one homogenous pattern in acquisitions of equipment/technology and two heterogeneous patterns among policy design and development of product/technology.

4.3.3 Context and process of construction of evidence

This section presents results to determine the relevance of the context and the process of construction of evidence in explaining the way indicators are used in decisions of technology innovation. The first sub-section presents a case study of a policy decision about electric mobility, and the second a decision to create a nanotechnology laboratory. Both sub-sections are structured the same way: they describe (a) the context of the decision process, (b) the social network organized to make a decision, and (c) the process of construction of evidence. The third and last sub-section compares the two social networks.

4.3.3.1 Case study on electric mobility infrastructure

This sub-section provides a description of the context of a decision to promote electric mobility in Portugal, involving policymakers and business R&D&I leaders. Afterwards, it includes a social network analysis to complement the description of the organizational context. The last part presents an analysis of the process of construction of evidence.

The history of electric mobility has been linked to the invention of technologies responsible for propulsion, such as the electric motor[95], the ICE[96] and batteries. The availability of resources played an important role in the development of electric vehicles (EVs), such as financial constraints and raw materials. A third element to take into account was the emergence and influence of stakeholders, such as governments, lobbies, consumers, etc. Furthermore, some authors have characterized the repeated revival of EVs (including hybrids) as a permanent "emerging technology syndrome" (Midler & Beaume 2010). The extent to which the present revival in EVs is part of this syndrome or a departure to meet another socio-technical regime remains to be seen.

A closer look at the development process of EV in Japan can help us to understand the role of government in the recent commercialization of battery electric vehicles (BEVs). In the 1970s, the Japanese government started to design and implement a comprehensive, long-term strategy to electrify vehicles (Åhman 2006). It included an R&D programme and a demonstration programme, as well as the creation of niche markets, legislation and standards. The government was a driver in a long-term development process to end Japanese oil dependency. At that time, Japan had a strict Basic Law for Environmental Pollution Control and faced Californian pressures for fewer vehicular emissions (Rosenbluth and Thies 2002; Pohl and Yarime 2012). However, in the early 1970s the government lacked credibility in industrial policy. This was partly due to the fact that most companies were

[95] This history dates back to the early nineteenth century, when inventions in the field of electrical science started to appear. At the time, there were many inventors across the globe trying to create an electric propulsion mechanism to propel various types of vehicles (Doppelbauer 2013). For the most part, however, inventors worked in national contexts and knew nothing about each other's work (Doppelbauer 2013). Several authors traced back the first electric vehicle (EV) to the year 1827, when the Slovak-Hungarian Benedictine priest Ányos István Jedlik built the first crude but viable electric motor (Heller 1896; Guarnieri 2012; Chan 2013).

[96] ICE is the acronym for Internal Combustion Engine.

unwilling to cooperate with the government, for fear of exposing industrial strategies to their national competitors (Åhman 2006). Nevertheless, the car industry eventually collaborated with the Ministry of International Trade and Industry to avoid being excluded from the group of companies favoured by the central government (Åhman 2006). Furthermore, after the 1990s, the long-term government ambitions to produce an EV appeared to have failed. However, the ambition was instrumental in creating a commercially viable generation of hybrids (Åhman 2006). In fact, the hybrids benefited from technical development and experience gained through years of government support, primary aimed at BEVs. In 1997, the sudden launch of the hybrid Prius by Toyota even caught the government by surprise (Åhman 2006). More than one decade later significant developments occurred in Japan. In 2010 the long-term efforts of the Japanese government started to show concrete commercial results with the mass production of the Nissan Leaf and the Mitsubishi i-MiEV.[97] Although it is too early to identify the next dominant regime in the industry, the Japanese efforts led to an unexpected industrial differentiation among automotive producers: Nissan focused on BEVs, Honda on fuel cell vehicles and Toyota on hybrid electric vehicles (Pohl & Yarime 2012). Looking back, it is difficult to disregard the impact of having a continuous, stable and oriented national policy on the electrification of vehicles. In fact, without the influence of policymakers and their persistent investments, the success in sales of the hybrid Toyota Prius and the BEV Nissan Leaf (and Mitsubishi MIEV) may have never existed.

(a) Context of the decision

The Portuguese government elected by a clear majority in 2005 found favourable conditions for engaging in the promotion of technological change. The government supported sound policies towards renewable energies, and believed that they could technologically push for promotion of Portuguese development. At the same time, the positive economic outlook of the country was balanced with an increasing dependence on costly oil imports, thus calling for measures to de-carbonize the transport sector. Therefore, in early 2008, the government decided to create a working group of electric mobility to develop infrastructure for EV street charging. The national programme, hereafter codenamed EMobi, was officially launched in mid-2009.[98] Its pilot phase ended in June 2011, with the full implementation of 1300 slow charging posts and 50 fast charging stations, spread across the country, in streets, public parking lots, service stations, airports, hotels and shopping centres.[99] A payment system was also implemented to connect personal communication devices (e.g. tablets, smart phones, etc.). By enabling the user to select the most appropriate operation, the system allowed for an analysis of mobility costs in order to optimize energy consumption.[100] Furthermore, the EMobi charging

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[97] The first successful fully electrified car was commercially introduced in Japan and the United States in December 2010.

[98] Resolução do Conselho de Ministros n.º 20/2009. Diário da República, 1.ª série — N.º 36 — 20 de Fevereiro de 2009.

[99] "Electric Mobility - Portugal Showcase to the World – Institutional presentation". 2010. GAMEP - Gabinete de Apoio à Mobilidade Eléctrica em Portugal.

[100] "Mobi-E Electric Mobility - Portugal Showcase to the World". Mobi-E. November 2010.

stations were supported by the government, through a public innovation support fund created as a counterpart for the granting of wind power licenses (Godinho, Mamede, and Simões 2013). The power company EDP also made initial investments in supply electricity and continues to support the system's maintenance (costs of around 600 000€/year[101]) (I18).

The initiative was an official partnership between the government and Inteli - a think-tank consultancy company associated with the Ministry of Economy.[102, 103] The group included other companies such as: CEIIA - a non-profit private organization and a shareholder of Inteli.[104, 105] The organization is mostly a publicly-funded technology centre known for the development of an EV prototype;[106,107] EDP - the national energy utility at the time, in charge of integration with the grid; Siemens, Efacec and Martifer - three technology companies dealing with the charging solution; and Critical and Novabase - two information technology companies, in charge of the information technology solution. The qualifications of the members of the partners were at Bachelors or, sometimes, a Masters level in engineering. Furthermore, the public powerhouse EDP had a categorical interest in being part of the consortium of EMobi. The electric charging posts represented a business opportunity to enter a new market with a low investment, and a chance to be connected to an advanced technology process. On average, one electric car represents the equivalent of one energy client in Portugal (I18).[108] EDP offered free electricity until 2014 at least. Although the costs are relatively low for EDP, the initial expectations of 160000 electric vehicles in 2020 were decreased to 26000 (I18). In addition, there were other companies interested in the electric mobility market as well (I22). After settling a pilot test with EDP, the government/Inteli partnership decided to invite other companies.[109] To the oil and gas company GALP, it was an invitation that could represent a business opportunity to expand into the electricity distribution market (I18). However, GALP maintained some distance from the project because the initial expectations were high and later moderated (I22 and TIS.PT 2011).

The targets for installation of public chargers of EVs were ambitious for the internal market. In fact, the difference between supply of public charging posts and the actual demand can be seen both in the low number of EVs[110] in the country and the consumption of energy in the system. The number of existent EVs in Portugal was low in 2011 and 2012. In fact, there were only 193 EVs sold in 2011, and only around 300 EVs used the EMobi service in 2012 (I18). Furthermore, the energy consumption in the EMobi system was equivalent to 11 vehicles in 2012 (I18). In fact, only 4% of the electric vehicle

[101] According to 2012 costs.
[102] "Inteli - Institutional Information." Last accessed in 21/12/2014. http://inteli.pt/en/go/fichainstitucional.
[103] "Mobi-E Electric Mobility - Portugal Showcase to the World". Mobi-E. November 2010.
[104] CEIIA. "CEIIA Institutional Information." Last accessed in 21/12/2014. http://www.ceiia.com/general-information/.
[105] "Inteli - Institutional Information." Last accessed in 21/12/2014. http://inteli.pt/en/go/fichainstitucional.
[106] CEIIA. "CEIIA Institutional Information." Last accessed in 21/12/2014. http://www.ceiia.com/general-information/.
[107] "Mobi-E Electric Mobility - Portugal Showcase to the World". Mobi-E. November 2010.
[108] Assuming the car runs 10000 Km/year.
[109] In 2013, there were five other energy suppliers of electric mobility in Portugal.
[110] Electric cars or e-cars account for a very significant portion of EVs.

fleet charged their batteries using the public infrastructure (I18). The remaining 96% of the EV fleet charged privately, and relatively inexpensively, at the price of 1.3 €/day (equivalent to 39 €/month) (I18). Furthermore, there are two other reasons that may be linked to the underperformance of the EMobi charging system: the cable and illegal parking. According to one user, an internally connected cable should have been included in the design of the charging station: by requiring users to carry and use a costly charging cable, consumers run the risk of robbery during charging periods (I19). Moreover, there were (moderate) signs of illegal parking by non-electric vehicles in the public charging slots (I21).

(b) Social network

The methods used to study the EMobi case allow for an identification of the relationships between the main actors involved in the decision process. The relationships between the actors form a social network of those involved in the collective effort of designing the electric mobility policy. The following social network analysis focuses on the structure of this network, and other measures of its cohesion and shape.

Sociogram

The main relationships between actors in the decision process can be depicted in a graph of the interrelations created during the decision. The following figure is a sociogram representing the structure of the EMobi network, formed by the interpersonal relations between actors during the decision process. The figure is based on the sociomatrix[111] of the weighted interrelations between decision makers (see Table 7.3 in Annex 3 – Supplementary tables).

[111] A sociomatrix is a two-way relational matrix where the rows and columns refer to the actors making up the pairs (Wasserman and Faust 1994).

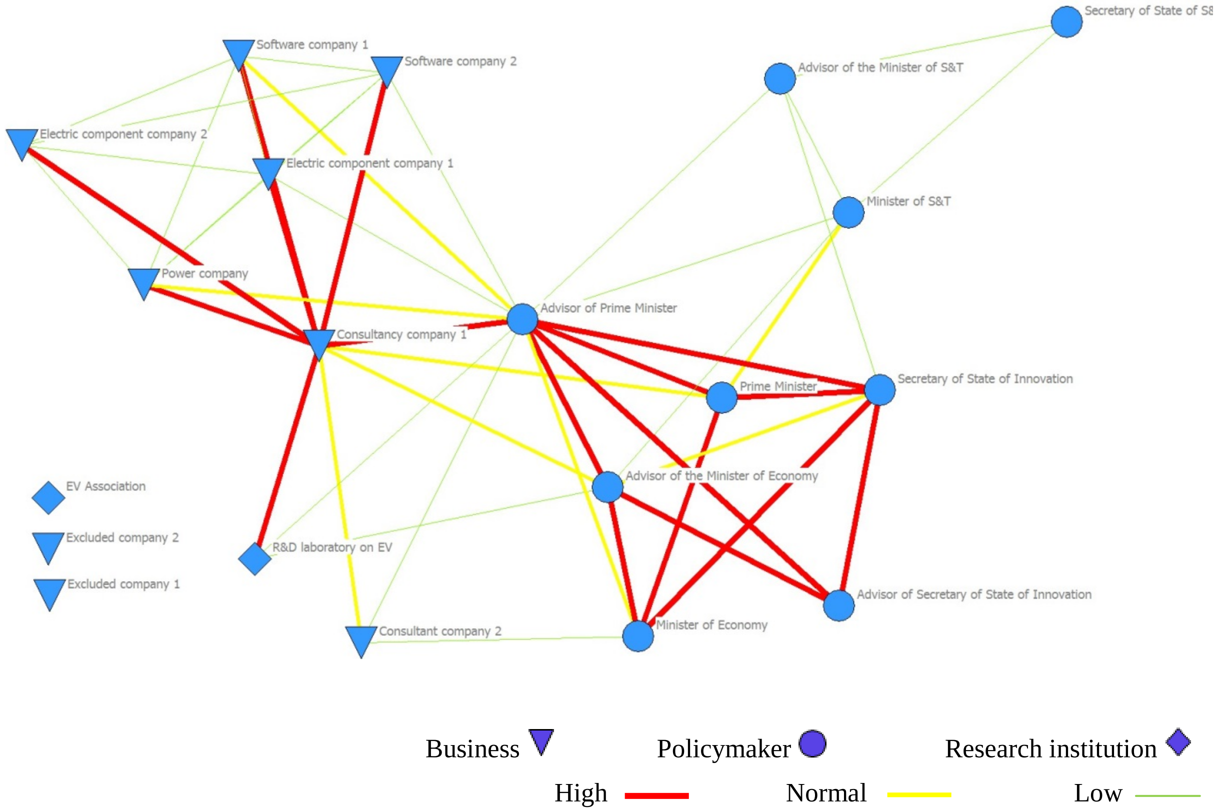

Figure 4.2 – Sociogram of the network of decision-making in EMobi

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

Figure 4.2 presents three main features concerning the relationships between actors in the process. First, it reveals one group on the left side mainly composed of companies, and another group on the right side mainly composed of policymakers. Second, the figure captures the centrality of the Advisor to the Prime Minister and Consultancy company 1 in the decision process. Third, the figure reveals other less influential actors significantly involved in the decision process, such as the Prime Minister, Advisor to the Minister of Economy, the Minister of Economy, the Secretary of State of Innovation and the Advisor to the Secretary of State of Innovation. In sum, the EMobi decision resulted significantly from close interaction between two groups of actors: companies and policymakers.

Cohesion

The analysis of the social network also provides measures related to its cohesion. The following table presents several cohesion measures of the EMobi network.[112]

[112] See Ucinet Log 1 – Multiple Cohesion measures EMobi in Annex 4 – Ucinet files.

Table 4.12 – Network cohesion measures of EMobi

	Network Cohesion	Measures
1	Avg Degree	4,800
2	H-Index	6,000
3	Centralization	0,538
4	Density	0,253
5	Components	4,000
6	Component Ratio	0,158
7	Connectedness	0,716
8	Fragmentation	0,284
9	Closure	0,542
10	Avg Distance	1,765
11	SD Distance	0,656
12	Diameter	4,000
13	Breadth	0,529
14	Compactness	0,471

Notes: The centralization measure is Freeman's degree centralization. Density, connectedness and compactness can vary in the interval [0, 1]. The comma is used throughout this work to indicate decimal mark. Values were calculated using UCINET 6 for Windows. (Borgatti, Everett, and Freeman 2002).

The idea of cohesion in a social network can be related to a combination of measures. To comprehend the cohesion of this network, three measures depicted in Table 4.12 are particularly relevant: density, connectedness and compactness. The table reveals that the density of the network of EMobi is low-medium (0,253) when compared with Richardson's (2009) study where a density of 0.0188 was considered sparse. Furthermore, connectedness (the opposite of fragmentation) provides an idea of how connections are distributed throughout the network (Borgatti, Martin, and Johnson 2013).[113] The table shows that the value of connectedness in the network is 0,716, which represents a significantly connected process. In addition, if things flowing through the network can reach nodes quickly, the network has a certain kind of compactness, according to the authors. The table reveals the value of compactness to be 0,471, representing a normal flow of information through the network. In sum, the measures indicate that the networks' density is low-medium, that there is a significantly connected process, and that the structure presents normal values of compactness.

Shape

Another class of network characteristics are shape measures of the network. In this case, the shape measures can include properties such as centralization, core-peripheriness and the existence of sub-groups (or factions). Centralization refers to the extent a network is dominated by single node

[113] It is defined as the proportion of pairs of nodes that can reach each other by a path of any length (i.e. the proportion of pairs of nodes located in the same component).

(Borgatti, Martin, and Johnson 2013).[114] The table reveals that the centralization value of the network is 0,538, a middle value. The following analysis will only consider centrality at the individual level.

Individual centrality reveals the advantage some nodes have by virtue of their central position in the network, such as information, influence or power. It is important to identify who is central when trying to get something done. In fact, "a node might be central in the sense of being able to control the flow of information, whether in the sense of filtering key bits or passing it along but colouring it in ways that benefit the node" (Borgatti, Martin, and Johnson 2013). The following table presents individual centrality measures in the sociomatrix of the network (see Ucinet Log 1 – Multiple Cohesion measures EMobi in Annex 4 – Ucinet files).

Table 4.13 – Individual centrality measures of the EMobi decision makers

	Centrality		
Actors	Eigenvector	Closenes	Between
Prime Minister	0,204	42,000	2,444
Consultancy company 1	0,379	38,000	16,290
Advisor of Prime Minister	0,454	33,000	54,154
Advisor of the Minister of S&T	0,126	44,000	6,150
Secretary of State of S&T	0,042	56,000	0,000
Minister of S&T	0,159	43,000	8,967
Electric component company 1	0,281	42,000	1,144
Software company 1	0,281	42,000	1,144
Power company	0,281	42,000	1,144
Software company 2	0,281	42,000	1,144
Electric component company 2	0,222	49,000	0,000
Consultant company 2	0,151	45,000	0,375
EV Association	0,000	95,000	0,000
Excluded company 1	0,000	95,000	0,000
Excluded company 2	0,000	95,000	0,000
R&D laboratory on EV	0,160	45,000	0,000
Advisor of the Minister of Economy	0,247	40,000	6,527
Minister of Economy	0,186	44,000	1,367
Secretary of State of Innovation	0,200	42,000	3,150
Advisor of Secretary of State of Innovation	0,133	46,000	0,000

Notes: Values were calculated using UCINET 6 for Windows. (Borgatti, Everett, and Freeman 2002).

Table 4.13 presents three main features of individual centrality:

1. The table reveals that the Eigenvector centrality is significantly higher in two nodes (1 and 2): The Advisor to the Prime Minister node has 0,454, followed by the Consultancy company 1 with 0,379. Furthermore, the table also identifies three other actors excluded from the decision process, i.e. the EV Association, Excluded company 1 and Excluded company 2 (all with 0). These measures confirm previous information captured during the interviews, where the central two actors were described as highly centralized decision makers (I7 and I18); and other potentially

[114] According to the authors, a maximally centralized graph looks like a star: the node at the centre of the network has ties to all other nodes, and no other ties exist.

interested actors were not taken into account, such as the Portuguese Association for Electric Vehicles and other competing companies (I20, I21 and I22). In sum, the network is significantly centred on the Advisor to the Prime Minister and to a lesser extent on Consultancy company 1, while some actors were not included in the process.

2. Another measure of the shape of the network is closeness centrality.[115] Closeness gives an indication of how long things take, on average, to reach a given node. In fact, closeness is an inverse measure of centrality in the sense that large numbers indicate that a node is highly peripheral, while small numbers indicate that a node is more central.[116] In this context, closeness centrality can be interpreted as an inverse measure of influence in the decision process.

   Table 4.13 confirms that the same actors are very close to the centre, i.e. Advisor to the Prime Minister and Consultancy company 1 (with 38 and 39 respectively). However, the values for most of the other actors were not substantially distant, varying from 42 to 56. Excluded actors had 95, representing the most distance. In conclusion, the network presents a shape closed closely around its centre.

3. Another measure of the shape of the network is betweenness, usually interpreted as the potential for controlling flows through the network.[117] A node with high betweenness is in a position to threaten the network with disruption of operations or, more generally, to filter information and to colour or distort it as actors pass it along. In fact, a node (or actor) with high betweeness has power because it can threaten to stop transmitting, forcing nodes to use less efficient paths to reach one another.

   Table 4.13 presents results pointing to four main characteristics. First, there is a significant high score of betweenness for one core actor (i.e. Advisor to the Prime Minister with 54,154). This effect of control of information was confirmed in two interviews (I7 and I16). Second, Consultancy company 1 has a medium score of 16,290. Third, the table presents medium-low scores for five secondary actors: Minister of S&T with 8,967; Advisor to the Minister of Economy with 6,527; Advisor to the Minister of S&T with 6,15; Secretary of State of Innovation with 3,15; and Prime Minister with 2,444. Fourth, the table presents null scores (or near) for the remaining thirteen actors.[118] These results confirm the information previously collected, in which a powerful

[115] According to Borgatti, Martin, and Johnson (2013), closeness centrality can be calculated using Freeman's definition: the sum of geodesic distances from a node to all others (i.e. the length of the shortest path connecting them).
[116] In a flow context, closeness centrality is typically interpreted in terms of the minimum time until arrival of something flowing through the network. According to Borgatti, Martin, and Johnson (2013), a node that has a highly normalized closeness score is a short distance from most others, so information originating at a random node can potentially reach the central node very quickly. The authors also argued that since the diffusion process tends to introduce distortion, the information received by central nodes have higher fidelity on average. Consequently, a highly normalized closeness is a significant advantage for a node (in the case of something useful is transmitted).
[117] According to Borgatti, Martin, and Johnson (2013), betweeness centrality reflects the amount of brokerage each node has between all other nodes in the network.
[118] Namely, the Minister of Economy, Secretary of State of S&T, Electric component company 1, Software company 1, the power company, Software company 2, Electric component company 2, Consultant company 2,

core filtered information when passing it along (I7, I16 and I25). In conclusion, the network presents a shape dependent on flow, significantly controlled by the Advisor to the Prime Minister.

In sum, the three measures of individual centrality indicate the existence of powerful central decision makers within a close-to-the-centre network of decision makers. These results also align with information collected during interviews. In fact, these measures confirm previous results where policymakers far from the small centre of a decision did not have access to parts of important information (I7, I16, I18 and I21).

Another network characteristic similar in spirit to centralization of the network is the core-periphery structure (Borgatti, Martin, and Johnson 2013). Measures of the core-periphery of a network essentially result from comparing the network with an idealized model. Core-periphery structures are commonly found in social network data, and have important implications for the functioning of networks. Figure 7.1 (Annex 2 – Supplementary figures) reveals that a central core (labelled 1) and a periphery (labelled 2) exist in the network of decision of EMobi. The core is composed of the Prime Minister, Consultancy company 1, Advisor to the Prime Minister, Advisor to the Minister of Economy, Minister of Economy, and Secretary of State of Innovation. The periphery is composed of the remaining actors of the network.[119] These findings are in accordance with the idea expressed by two interviewees, who revealed the existence of a centralized core in the decision process (I7 and I21). It can be concluded there was a core composed of powerful actors, and an inherent periphery among the remaining decision makers.

A network can also include inside subgroups. The analysis of cohesive subgroups (also referred to as communities) can help to understand the functioning of a network. In fact, these subgroups are portions of the network in which actors interact more with each other than they do with actors who are not in the subgroup. These types of subgroups often share common ideals, goals and/or attributes and form factions within the network (Borgatti, Martin, and Johnson 2013). In social network analysis, calculating factions is a method that partitions the whole population into a predetermined number of cohesive subgroups. Figure 7.2 (in Annex 2 – Supplementary figures) reveals the existence of three factions in the network. The first faction is composed of all instrumental companies in the process of implementing EMobi.[120] This faction is the business group composed only of companies with particular commercial interests in the project. The faction includes Consultancy company 1, which could be also part of the third faction. The second faction is composed of actors who played a minor or

the EV Association, Excluded company 1, Excluded company 2, R&D laboratory on EV and the Advisor to Secretary of State of Innovation

[119] Namely, the Advisor to the Minister of S&T, Secretary of State of S&T, Minister of S&T, Electric component company 1, Software company 1, the power company, Software company 2, Electric component company 2, Consultant company 2, EV Association, Excluded company 1, Excluded company 2, the R&D laboratory on EV, and Advisor to Secretary of State of Innovation.

[120] Namely, Consultancy company 1, Electric component company 1, Software company 1, the power company, Software company 2, and Electric component company 2.

no role at all in the decision process.[121] The third faction is composed of all actors with an active mobilization role in policy-making.[122] This faction functioned as the public promoters of the EMobi project. However, two elements were controversially assigned to this faction by Ucinet: First, the R&D laboratory for EV is in reality a research laboratory significantly subsidized by the state, although officially a non-profit private organization.[123] While its official alignment was close to the commercially oriented faction[124], their research interests are more aligned with public research. Therefore, it is tolerable that it falls in the active policy faction. Second, Consultancy company 2 was instrumental in providing policymakers with evidence to pursue their policy. Its private interests are related to the creation of evidence for public policy. Therefore, the third faction is entirely composed of actors active in policy-making as well as two special cases. The latter actors were not significantly relevant, mostly instrumental to the decision-making process, and possessed a hybrid interest in the promotion of the policy: public and commercial. In sum, the analysis revealed that one faction represented commercial interests, the second represented those excluded or distant from the policy, and a third faction was composed entirely of actors active in public policy-making.

To conclude, this social network analysis expanded upon the organizational context of the decision-making process of EMobi. In fact, the complete analysis of this case study penetrated and made explicit the organization and interest in the project. Furthermore, the tools available in social network analysis provided empirically validated indicators of structure, cohesion and shape of the network and individual actors. The case study allowed an analysis with objective measures for links between decision makers in a network, which evolved organically to implement a policy decision about electric vehicles.

(c) Process of construction of evidence

The decision makers of EMobi constructed a rationale to support their decision (I7 and I9).[125] A central argument used to justify the decision was that "the lack of a charging infrastructure deters the acquisition of electric vehicles" (Pinto et al. 2010, p.15). However, two interviewees explained that the decision was not so much based on the technological effect of the policy, but rather on its political and social impact (I9 and PI9). Furthermore, technical evidence was sought after the decision was made (I7 and I9).[126] The central evidence supporting the EMobi decision was based on an indicator of market penetration for EVs in 2020. This indicator was based on an optimistic scenario for the fleet of

[121] Namely, the Advisor to the Minister of S&T, Secretary of State of S&T, Minister of S&T, the EV Association, Excluded company 1, and Excluded company 2.
[122] Namely, the Prime Minister, Advisor to the Prime Minister, Consultancy company 2, R&D laboratory for EV, Advisor to the Minister of Economy, Minister of Economy, Secretary of State of Innovation, and Advisor to Secretary of State of Innovation.
[123] CEIIA. "CEIIA Institutional Information." Last accessed on 21/12/2014. http://www.ceiia.com/general-information/.
[124] The R&D laboratory on EV partially owns Consultancy company 1 as a private entity.
[125] "Modelo de Mobilidade Eléctrica Para Portugal – Apresentação a Sua Excelência O Ministro da Economia e Inovação – Sumário Executivo". Presentation. Roland Berger Strategy Consultants. Lisboa. 14/1/2009.
[126] "Modelo de Mobilidade Eléctrica Para Portugal – Apresentação a Sua Excelência O Ministro da Economia e Inovação – Sumário Executivo". Presentation. Roland Berger Strategy Consultants. Lisboa. 14/1/2009.

EVs presented by the government: according to the forecast of the coordinator of the Office for Electric Mobility, in 2020 Portugal would have 750000 electric vehicles (Gomes 2010). But, according to a study by Paulo Santos in 2009, there will be no more than 600000 electric vehicles in 2020 in a “very” optimistic scenario (Santos 2009, 40). Moreover, according to Luís Gomes (2010), the governmental forecast was optimistic because EVs represented 80% of the sales in 2020 (reflecting a sales growth rate of 1%). In fact, his study forecast an optimistic scenario with a penetration rate of only 50%, predicting just 322027 electric vehicles in 2020 (Gomes 2010). Therefore, the programme was decided based on political and social considerations, included evidence based on optimistic scenarios and disregarded other existing evidence.

To better understand the optimistic nature of the evidence brought to support the decision, it is necessary to take into consideration other forecasts. For example, an expert from the Portuguese Automotive Business Association (ACAP) reportedly stated that only in a “very” optimistic scenario 300000 vehicles were expected to be sold in the year 2020 (Santos 2009). This forecast implied an optimistic increase both supported by the ratio of population/sales of cars existent in countries like Belgium and the Netherlands, as well as in the assumption that in 2020, Portugal will reach these countries’ economic and social development (Santos 2009). Furthermore, there was further evidence available, although even these proved distant from reality. First, Gomes' (2010) short-term calculations for a pessimistic scenario for 2011 and 2012 even exceeded reality. The author forecast 394 electric vehicles in 2011, but only 193 electric vehicles were sold in Portugal during that year (Beltramello 2012 based on Frost & Sullivan 2012). Gomes also calculated 999 electric vehicles in 2012, but there were only around 300 vehicles on Portuguese roads[127]. Second, the most pessimistic scenario of the two pessimistic considered in Santos' (2009) study, predicted a meagre presence of electric vehicles in 2020 with only 80000 units. The author described this latter scenario as “catastrophic”, given the “significance of public and private investments expected” to create the infrastructures and fiscal benefits for acquiring electric vehicles (Santos 2009, 44). Santos also added that this was a very unlikely scenario, “justified by the non-acceptance of this king of technology in the automotive market” (Santos 2009, 44). Third, two other studies provided further evidence in 2010 and 2011. A study contracted by GALP showed that the penetration forecast of the electric vehicle would be significantly slow (I7, line 211-214 and TIS.PT 2011). Reiner et al. (2010) also forecast an optimistic technology scenario where BEVs and fuel cell vehicles would have penetrated only 5% of the European market in 2020. Therefore, other disregarded evidence existed before the final implementation of the policy pointing to a moderation of the expectations for the EV market.

Optimistic studies forecasting the advent of EVs were not a uniquely Portuguese experience. In fact, Midler & Beaume (2010) reported the existence of three scientific studies in the United States predicting the introduction of EVs. The first one in 1973, elaborated by the Wisconsin University, forecast a penetration rate of 20% of the total sales in 1980 in the USA. In 1979, a Princeton

[127] “Mobi.europe Newsletter”. Mobi.europe. September 2012.

University study forecast a slower penetration rate (10%) in 2000. Later, in 1994, the World Resources Institute predicted a 25% penetration rate in US total sales by 2010. Since market penetration is still significantly low, it is clear that these studies were significantly optimistic.

There are elements to conclude that other evidence played a role in the decision process. For example, an international consultancy group and a national consultancy company produced evidence to influence policy-making. In fact, the consultancy group was hired by the government to elaborate a technical report on electric mobility, and to specify technical features for public charging stations (I21).[128] The report forecast an optimistic potential market of 180000 EV and Plug-in Hybrid Electric Vehicle for 2020, with 25000 slow charging public posts and 560 fast chargers (I21). This firm also calculated that EVs were 11% more competitive than normal ICE[129] for private owners and 12% so for companies. Another firm solicited a study from a national consultancy company and distributed the results to influence policy outcomes (I22). Some elements of the study benefited the firms' strategy in the short-term, and influenced policy-making in matters of market-share, norms and regulations related to EVs in Portugal (I22). Forecasts were significantly cautious about the growth of the EV market (TIS.PT 2011), substantiating controversies about initial governmental claims (I22). Therefore, there are elements to conclude that adicional evidence were introduced in the policy process to influence the final decision in a controversial context.

In sum, the EMobi programme was mainly based on political and social considerations. The evidence used to support the decision were based on optimistic scenarios. Other disregarded evidence existed before the implementation of the decision, and pointed to moderation in expectations for the EV market. Additional evidence were privately solicited to companies to influence the policy-making process. The government used their optimistic forecast as evidence towards good policy, focused on an indicator of market penetration of EVs in 2020, and disregarded other existing evidence. However, time showed that all forecasts were weak evidence to support the policy decision. Moreover, the subcontracting of think-tanks also produced technical evidence to influence the policy process. As such, this case served as an example of the disputed nature of evidence and indicators in policy-making, as discussed in the literature. In fact, what constituted an indicator was debated, influenced by various parties, indicators lost strength through controversy; or were ignored if unhelpful.

[128] "Modelo de Mobilidade Eléctrica Para Portugal – Apresentação a Sua Excelência O Ministro da Economia e Inovação – Sumário Executivo". Presentation. Roland Berger Strategy Consultants. Lisboa. 14/1/2009.

[129] ICE is the acronym of Internal Combustion Engine.

4.3.3.2 Case study on the nanotechnology laboratory

This sub-section first provides a description of the context of the decision to create a nanotechnology laboratory, involving policymakers and scientists. Afterwards, it proceeds with a social network analysis to provide a comprehensive view of the organizational context of the decision. The last part includes an analysis of the process of construction of evidence during the decision process.

Nanotechnology is frequently considered an advanced interdisciplinary scientific area and an emerging technology (Robinson 2009; Heinze et al. 2007; and Barben et al. 2008). It can be defined as a heterogeneous set of technologies applied to or using systems at the nanoscale (Fleischer and Grunwald 2008; OECD 2010). Nanotechnology and nanoscience deal with material structures at the nanoscale, defined as a dimension between 1 to 100 nanometres.[130] Despite controversies over its definitions, a nano component can be a decisive part of a complex product, although its content might not be easily detectable. Furthermore, some experts assert that nanotechnology has the potential to produce innovations rendering numerous benefits, in particular contributions to economic prosperity and to sustainable development (Fleischer, Decker, and Fiedeler 2005). In fact, although not many innovations exist presently in the market,[131] nanotechnology could potentially be used in a wide range of applications such as ICT[132], food quality control, medicine and biotechnology. The few existing products focus on health and fitness, home and garden, food and beverage, electronics and computers, automotive and children's goods (OECD 2010). Nevertheless, most developments still relate to scientific findings apart from concrete final product innovations.

Technology decisions in nanotechnology policy face four significant challenges. First, the scientific controversies over its definition and scale are often complemented with questions on whether it is a specific technology or even a definitive group of technologies. Consequently, scientists, policymakers and lay people carry their own heterogeneous conceptions of what nanotechnology is in their arguments during discussions, creating difficulties with communication, public participation and community involvement (Fleischer, Decker, and Fiedeler 2005). Second, decision-making faces high uncertainty about effects and impacts. On one hand, nanotechnology could potentially lead to less use of scarce and polluting materials and it could be a critical component of sustainable development (Fleischer and Grunwald 2008). On the other hand, potential for side effects is significant. In fact, little is known regarding potential environmental and health impacts of nanomaterials, despite many research initiatives throughout the world, according to the authors. Third, regulatory agencies often act

130 Some experts argue that magnitude should not be included in its definition (see Fleischer, Decker, and Fiedeler 2005).

131 See for example the inventory of nanotechnology-based consumer products introduced on the market (Project on Emerging Nanotechnologies 2013).

132 ICT is the acronym of Information and Communication Technologies.

in the absence of data about toxicology and effects (Morris et al. 2011). In fact, the data on the levels and identity of nanomaterials are either limited or non-existent, making it difficult to quantify exposures (Morris et al. 2011). Fourth and last, decision-making requires shared responsibility between regulators and producers of nano products. In fact, some information about characteristics, performances and protection can only be obtained by the scientists and engineers involved in the development of nano products (Morris et al. 2011).

(a) Context of the decision

The idea to create a nanotechnology laboratory, hereafter referred to as NanoLab, was initially defined in a governmental policy briefing during the preparation of the 2005 Summit between Spain and Portugal. The briefing consisted of half a page with political ideas and technical benefits of the proposal (I25). Both the scientific area and the location of NanoLab were intentionally left open. In fact, these definitions would be the result of not only negotiations between the two governments, but also the outcome of discussions among government members (I25). At the time, there were several proposals in various scientific fields to be discussed between both countries, such as nanotechnology, grid computing, biotechnology, biomedicine, energy and risk management (I25). There were also several proposals for different regions in Spain and Portugal to host the lab. Inside the Portuguese government, stronger candidates to headquarter the facilities were the border regions of Northern Alentejo (where the Évora Summit was held), and the Braga district, where nanotechnology research was stronger (I25). At the end of the Summit, the heads of state agreed to locate the facility in Braga, and nominated the Spanish José Rivas to be its Director-General (INL 2012).[133] The concept of an Iberian joint research laboratory was well received in both Spanish and Portuguese governmental circles for several reasons (I25): the laboratory would cement relations between countries separated by historical events and not prone to cooperate beyond necessary issues; the cooperation would lead to the creation of the first international research institution located in Spain or Portugal;[134] the research facility would be dedicated to an advanced scientific area and an emergent technology; and, the facility would be opened to participation of other countries, fostering international collaboration.

The agreement reached in the Summit included setting up a bilateral technical committee to prepare for the creation of the NanoLab. A newly created technical committee was tasked with the preparation of a detailed proposal, the definition of the initial lines of scientific and technical activities, the setting of the operation model of NanoLab, its funding, installation modalities, calendar and possible partnerships (I25). The committee was composed of two poles in each country controlled by several institutions (INL 2011a).[135] Members were to be scientists in possession of a doctorate.

[133] A Spaniard was nominated, given that the final location of the facility was in Portugal.
[134] The Institute for Prospective Technological Studies located in Seville is a European research facility of the Joint Research Centre[134] of the European Commission.
[135] In Spain it was controlled initially by three institutions on the part of the Ministry of Education and Science: the Directorate General of Research (DGI), the Directorate General of Technological Policy (DGTP) and the Directorate General of Universities (DGU). In Portugal, the control was exercised by four institutions on the part

Furthermore, the technical committee decided the strategic orientations of the NanoLab along four main lines (Technical Committee 2006a): It determined that NanoLab should assure world class research in all areas of activity; develop partnerships with the industry; foster the transfer of knowledge into economic value and jobs; train researchers; develop a skilled workforce for the nanotechnology industry; and prevent and mitigate nanotechnology risks. Second, the committee decided that the recruitment of human resources should be ambitious. It should hire the best teams of researchers from the beginning, to immediately assure an excellent reputation and enhance the attraction to top scientists and talented graduate students. Third, the committee requested a report about nanotechnology activity in Spain and Portugal from two scientists, already members of the committee and appointed Directors of the NanoLab[136] (INL Technical Committee 2006). Fourth, the technical committee designed a scientific strategy based not only on the former report but also on the critical recommendations of an International Advisory Board and two organizational and legal experts:

- The International Advisory Board played an important role in the NanoLab (I25 and I26). The board was composed of influential members of the nanotechnology and nanoscience international community (INL Technical Committee 2006). It included leaders of large research institutions who were able to secure initial training and establish significant relationships within the NanoLab.[137] It also included an influential player of a major initiative for nanotechnology in the USA (Roco et al. 2000). The board was directly involved in meeting and agreeing upon strategic suggestions by the committee, based both on the fields that received fewer R&D efforts in most countries and the existing Iberian capabilities (I26). The strategy was oriented toward four research areas: Nanomedicine, environment monitoring, security and food quality control, nanoelectronics (beyond CMOS[138]), and nano-machines and nanomanipulation. The area of environmental monitoring, security and food quality control was particularly well received (I26). Second, the board elaborated on an advanced training scheme for the first scientists of the NanoLab, which allowed the sending of the first post-docs to relevant research centres around the world (I26).
- Two international consultants were also pivotal to the setup of the NanoLab. Their experience was helpful in dealing not only with legal and governance issues, but also with administrative framework (I25 and I26). First, a legal advisor was hired with significant experience with several

of the Ministry of Science, Technology and Higher Education: Knowledge Society Agency (UMIC), the Science and Technology Foundation (FCT), the Science and International Relations Office of Science and Higher Education (GRICES) and the Council of Associated Laboratories (CLA).

[136] Professor José Rivas related to [this is super awkward wording; what do you mean by related to?] the University of Santiago de Compostela in Spain and Professor Paulo Freitas related to the Technical University of Lisbon in Portugal.

[137] Namely Roberto G. M. Caciuffo (European Commission, Joint Research Centre, Karlsruhe), Thomas Jovin (Max Planck Institute for Biophysical Chemistry, Göttingen), Emilio Mendez (Center for Functional Nanomaterials - Brookhaven National Laboratory, Upton, New York), Christopher B. Murray (University of Pennsylvania, Philadelphia), Aristides A. G. Requicha (University of Southern California, Los Angeles) and Mihail C. Roco (National Science Foundation, USA).

[138] CMOS is the acronym of Complementary metal–oxide–semiconductor. CMOS is a technology for constructing integrated circuits.

international research laboratories in Europe, such as the CERN[139], ESO[140], EMBL[141] and ESRF[142] (I26).[143] The legal advisor also helped to elaborate on statutes and, later, staff rules (I25 and I26). His major governance advice was to include more countries in the laboratory, as soon as possible, to avoid continuous conflicts regarding legal aspects, particularly those not regulated by international law (I26). Second, the NanoLab also included a consultant on administrative issues - formerly the head of the administration of the ESRF - who provided detailed advice in relation to personnel, finance, purchasing/commercial activities, and general issues (INL Technical Committee 2006).

The decision-making process included further negotiation activities. In fact, the construction of the NanoLab comprised also two negotiation phases. First, it was necessary to find a city in the district of Braga to accommodate the NanoLab infrastructure. After the announcement of the launching of NanoLab in 2005, the technical committee awaited proposals from Portuguese municipalities within the district of Braga (I25). The Mayor of Braga proposed two locations in the city (I24). Guimarães, another major city in the Braga district, also presented two proposals (I24 and I25). In the end, the technical committee chose a property in Braga, near the Campus of Gualtar of Universidade do Minho, with an area of about 47000m^2, granted for 50 years unless the purpose of its use changes (INL 2011b and I24). The second phase relates to the physical construction and setup of the NanoLab. Three main steps allowed for construction in a relatively short period of time and prevention of cost increases (I25). First, an Installing Commission and a General Assembly were formed to authorize a call that included the architectural project, the construction project, the construction itself, as well as calls to buy equipment. Second, a team from the Portuguese National Laboratory for Civil Engineering was assigned to manage and control the construction work. Third, a Headquarters Agreement between the states and NanoLab was signed to establish the status, privileges and immunities of the laboratory and its personnel. This agreement allowed for the transference of funds, contracting scientists and a tax-free system.[144]

The decision to create NanoLab was, however, a complex process for six main reasons: It resulted from of a long-term decision of the governments of Spain and Portugal to cooperate in future S&T joint ventures (INL Technical Committee 2006). Second, it involved an important co-finance of the

[139] European Organization for Nuclear Research.
[140] European Southern Observatory.
[141] European Molecular Biology Laboratory.
[142] European Synchrotron Radiation Facility.
[143] This advisor defined the NanoLab legally as a bilateral research centre in Europe, established within public international law with intergovernmental governance (INL Technical Committee 2006).
[144] In the end, the buildings were constructed in circa 26000m^2, comprising a main scientific building[144], an incubator and a social building that includes a gym, a kindergarten and a residence to accommodate visitors and temporary researchers (INL 2011b). The cycle of acquisition of equipment is around 10 years, and the construction of the building should last for forty to fifty years (I26).

European Union[145]. In fact, the initial operational costs of NanoLab were significant (estimated ±30 million €/year), and the installation of the facilities would amount to an additional investment of 30 million euros (I26).[146] Despite the positive economic outlooks for both countries at the time, the co-financing by the EU was considered critical for the decision process. Third, the laboratory was the first international research organisation in Spain and Portugal, and it was also the only one in Europe in the field of nanoscience and nanotechnology[147]. According to interviewees, NanoLab's creation could stimulate a scientific presence at the international stage by setting significant research facilities in an emergent S&T field (I25 and I26) in the Iberian Peninsula.[148] Fourth, the decision required a relatively long period of time to be accomplished. In fact, the decision process took almost six years to be finished and to allow scientific work in the laboratory (I25 and I26). In some research policy circles, it was assumed that given the examples of CERN[149] and other institutions, international research facilities were difficult to create and required a great deal of time to implement. Fifth, NanoLab facilities were conceived to receive a substantial number of employees. In fact, NanoLab was designed to accommodate 400 workers (200 scientists, about 100 PhD students and the remaining related to technical and administrative staff)[150]. Sixth, the initial scientific declarations committed NanoLab to recruit the scientific staff globally and based on merit; guarantee internationally competitive salaries and benefits; assure immigration and family regrouping schemes provided by the international organization status; guarantee about 30% of the scientific positions with a tenure track; open post-doctoral positions and PhD student fellowships to be awarded globally; and guarantee oversight by an international scientific committee. The creation of NanoLab was involved in a complex and ambitious decisions to secure its functioning within international scientific standards.

The conception of NanoLab was based on an international organisational model. The model had three main features:

[145] "Edificação Do Laboratório Ibérico Internacional de Nanotecnologia". Programa de Cooperación Transfronteriza Espana - Portugal 2007-2013. POCTEP. Last accessed in 21/12/2014. http://www.qren.pt/np4/2271.html

[146] Most of the funds for construction came from the European Regional Development Fund through the Operational Programme for Cross-border Cooperation: Spain – Portugal, 2007-2013 ("Edificação Do Laboratório Ibérico Internacional de Nanotecnologia". Programa de Cooperación Transfronteriza Espana - Portugal 2007-2013. POCTEP. Last accessed in 21/12/2014. http://www.qren.pt/np4/2271.html)

[147] Magalhães, Luís "Welcome Address in Name of Knowledge Society Agency (UMIC) and Science and Technology Foundation (FCT)." Lecture, Annual Forum on EPT on Smart Systems and Integration (EPoSS), IST, Lisboa, 8/10/2010.

[148] It should be noticed that at the time of the decision, several countries also promoted significant investments in nanotechnology, such as the National Nanotechnology Initiative in the USA (Roco and Bainbridge 2003; Roco et al. 2000; Pandza, Wilkins, and Alfoldi 2011).

[149] The European Organization for Nuclear Research.

[150] The personnel originated from Spain, Portugal and other countries, and covered fundamental and applied research and related industrial activities. NanoLab presently has around 85 researchers although they should already be 150 (I26).

1. NanoLab was initially planned as an institution like CERN[151] in the area of nanotechnologies (I24, I25 and I26). The CERN model was a complex international model of cooperation in a scientific area (e.g. high-energy physics), open to all countries interested in participating.
2. NanoLab included a specific strategy for employment. In fact, when a principal investigator is hired, a reasonable amount of money is made available (c.a. 750 000€ to 1 000 000€), including the possibility to hire two to four post-doctoral or junior researchers. There is a trial period of three to four years, after which the group is expected to start financing itself through the European Union, industrial contracts and/or intellectual property. Furthermore, although the human resources at NanoLab are supposed to rotate, up to 30% of permanent contracts are expected to be signed between the fourth and the sixth year (in exceptional cases nine years).
3. The idea of extending NanoLab membership to other countries existed since the beginning, as mentioned (Technical Committee 2006). In an early phase there were plans to extend membership to two European states, Latin American countries (Brazil, Argentina, Mexico and Colombia were possibilities) and an Asian country (India) (I26). However, the inclusion of other member states remains difficult. According to an interviewee, the recent crisis and austerity measures did not facilitate the project of expansion because they reflect negatively upon? NanoLab (I25 and I26). Nevertheless, there were concrete talks about including other members in NanoLab. Two interviewees mentioned preliminary negotiations to include two or three more countries (I25 and I26): Brazil has a collaboration agreement with NanoLab to allow access of researchers and students to the facilities, and to promote mobility among the different centres involved. There are ten research projects to coordinate (I26).[152] There is also a memorandum of understanding to strengthen scientific and technical cooperation between Argentina and NanoLab.[153]

(b) Social network

The interviews conducted for this case study allows for an identification of the relationships between the main actors involved in the decision process of NanoLab. As in the previous case study, the relationships between actors form a social network involved in the collective effort to launch the laboratory. The social network analysis focuses on the organizational context of the network and other measures of its cohesion and shape.

Sociogram

As in the previous case study, the main relationships between the actors of the decision-making process can be depicted in a graph of the interrelations created during the decision. The following

[151] The European Organization for Nuclear Research

[152] The main areas of cooperation between NanoLab and Brazil are in electronic nanodevices, nanostructures and nanoparticles for applications in nanomedicine, environment control and water and food quality monitoring.

[153] The memorandum intends to facilitate the access of Argentine S&T institutions, researchers, students and companies to NanoLab's research facilities. Source: "Argentina, Espana Y Portugal Firmarán Acuerdo de Cooperación En Materia de Nanotecnología." Informe de la Cooperación Sur-Sur en Iberoamérica. 12/3/2014. Last accessed in 21/12/2014. http://cooperacionsursur.org/informacion-del-programa/noticias-de-cooperacion-sur-sur/202-espana-portugal-y-argentina-firman-un-acuerdo-de-cooperacion-en-nanotecnologia.html

figure is a sociogram representing the structure of NanoLab organizational network. The figure is based on the sociomatrix of the weighted interrelations between decision makers (see Table 7.3 in Annex 3 – Supplementary tables).

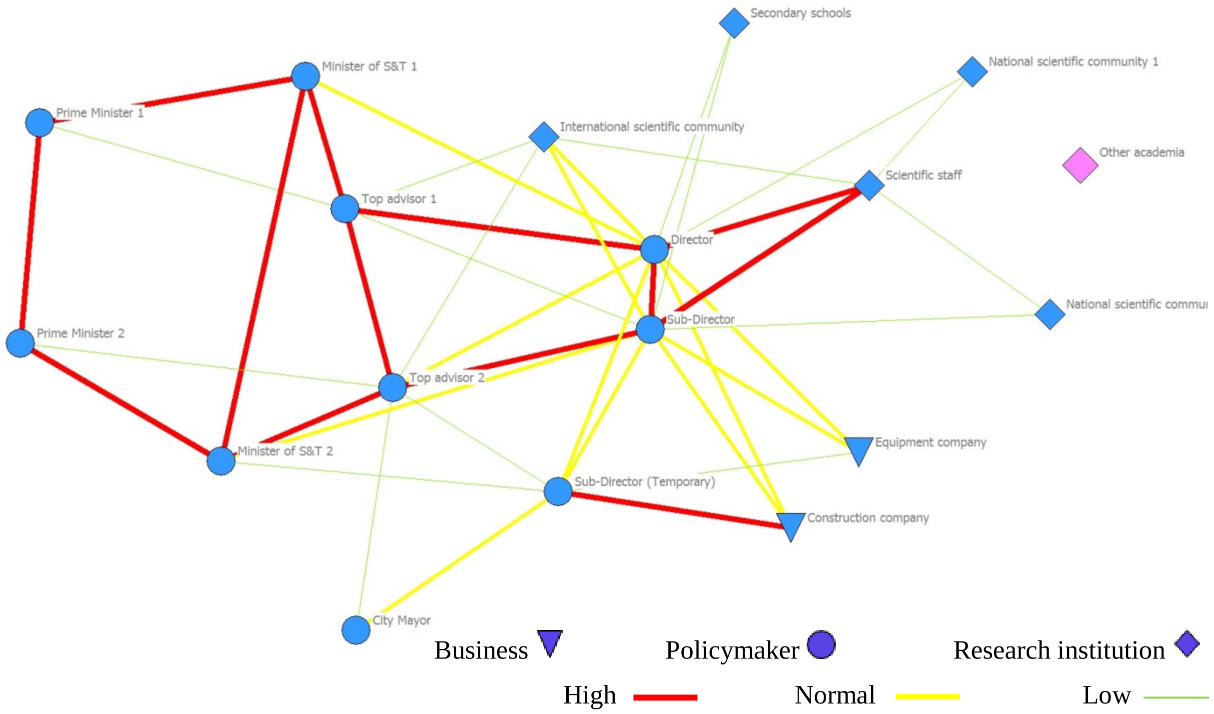

Figure 4.3 – Sociogram of the decision-making process of NanoLab

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

Figure 4.3 presents three main features concerning the relations between the actors in the decision process. First, it reveals one group on the left side mainly comprising policymakers, and another group on the right side containing scientists and two companies. Second, the figure captures the centrality of the governments, their top advisors and the directors of NanoLab in the decision process. Third, the figure reveals other less influential actors involved in the decision process, such as the City Mayor, a temporary director, two companies, the secondary schools, and excluded scientists in academia from different research areas. In sum, NanoLab structure resulted primarily from the negotiations between policymakers of the two countries, followed by decision makers acting both as policymakers and scientists.

Cohesion

A social network analysis of the NanoLab case, calculated using Ucinet, provides measures related to the cohesion of the network.[154] The following table presents several cohesion measures of NanoLab's network.

[154] See more details in Annex 4 – Ucinet files (Ucinet Log 5 – Multiple Cohesion measures NanoLab).

Table 4.14 – Cohesion measures in the decision network of NanoLab

	Network cohesion	Measures
1	Avg Degree	4,556
2	H-Index	5,000
3	Centralization	0,426
4	Density	0,268
5	Components	2,000
6	Component Ratio	0,059
7	Connectedness	0,889
8	Fragmentation	0,111
9	Closure	0,425
10	Avg Distance	1,853
11	SD Distance	0,659
12	Diameter	3,000
13	Breadth	0,444
14	Compactness	0,556

Notes: Values were calculated using UCINET 6 for Windows. (Borgatti, Everett, and Freeman 2002).The centralization measure is Freeman's degree of centralization.
Three measures are particularly relevant for understanding the cohesion in this network: density, connectedness and compactness.

Table 4.14 reveals that the density of the network of NanoLab decision process is medium-low (0,268).[155] Furthermore, a measure of connectedness provides an idea of how connections are distributed throughout the network (Borgatti, Martin, and Johnson 2013). The table shows that the value of connectedness in the network is 0,889, which represents a significant connected process, even more so than in the EMobi case. In addition, a network has a certain kind of compactness if things flowing through the network can reach nodes quickly, according to the same authors. The table reveals that the value of compactness is 0,556, which represents a normal flow of information through the network. The cohesion of the network is characterized by a medium-low density, significant connected process and normal compactness.

Shape

Another class of network characteristics is shape measures. In this case, these shape measures can include properties such as centralization, core-peripheriness and sub-groups (or factions) existent in the network. Centralization refers to the extent a network is dominated by single node, as mentioned before (Borgatti, Martin, and Johnson 2013).[156] The table shows the calculation of a medium value of centralization for the network (0,426).

[155] Here again, the value is medium-low, if one compares with the Richardson's (2009) study where a density of 0.0188 considered the network sparse.
[156]A maximally centralized graph looks like a star: the node at the centre of the network has ties to all other nodes, and no other ties exist, as mentioned before (Borgatti, Martin, and Johnson 2013).

As mentioned previously, individual centrality reveals the advantage some nodes have by virtue of their central position in the network, such as information, influence or power. It is important to identify who is central when trying to get something done or attribute a certain style of decision-making in the decision-making process. The following table presents individual centrality measures in the sociomatrix of the network of NanoLab.[157]

Table 4.15 – Centrality measures for the matrix of relations in the decision network of NanoLab

	Centrality		
Actors	Eigenvector	Closenes	Between
Prime Minister 1	0,088	41,000	1,000
Minister of S&T 1	0,163	34,000	3,819
Top advisor 1	0,279	30,000	9,795
Prime Minister 2	0,105	39,000	1,786
Minister of S&T 2	0,219	32,000	5,486
Top advisor 2	0,347	28,000	18,052
City Mayor	0,105	40,000	0,000
Director	0,426	25,000	32,369
Sub-Director	0,433	25,000	29,826
Sub-Director (Temporary)	0,307	30,000	9,050
Construction company	0,188	35,000	0,000
Equipment company	0,188	35,000	0,000
National scientific community 1	0,104	38,000	0,000
National scientific community 2	0,105	38,000	0,000
International scientific community	0,274	31,000	1,367
Scientific staff	0,216	34,000	3,450
Secondary schools	0,139	37,000	0,000
Other academia	0,000	68,000	0,000

Table 4.15 reveals three main features of individual centrality:

1. Both the Director and Sub-Director are significantly central to the network, presenting an Eigenvector centrality of 0,433 and 0,426, respectively. They were both popular actors. The Other academia group were excluded, with 0 Eigenvector centrality. These measures confirm previous results obtained in the interviews, where the former two actors were identified as key players in the decision process (I24, I25 and I26), and other scientists complained about exclusion from such a significant investment in S&T (I23 and CI2).
2. Another measure of the shape of the network is closeness centrality.[158] According to Borgatti, Martin, and Johnson (2013), large numbers indicate that a node is highly peripheral, while small numbers indicate that a node is more central. Table 4.15 reveals that the three actors are very close to the centre, i.e. Director and Sub-Director with 25 each, and Top Advisor 2 with 28. The values for most of the other actors were diverse, varying from 30 to 68 (more than in the EMobi network). In sum, results indicate a centralized decision process in three actors (i.e. Director, Sub-

[157] See more details in in Annex 4 – Ucinet files (Ucinet Log 6 – Multiple Centrality measures NanoLab).
[158] In this context closeness centrality can be interpreted as an inverse measure of influence in the decision process.

Director and Top Advisor 2), and a less centralized network of decision makers than the EMobi case.

3. Another measure of the shape of the network is betweenness centrality, usually interpreted as the potential to control flows through the network, by playing a gatekeeping or toll-talking role (Borgatti, Martin, and Johnson 2013). As previously stated, a node (or actor) with high betweeness has power because it can threaten to stop transmitting by making nodes use less efficient paths to reach one another. The analysis of Table 4.15 reveals four main features: First, there are high scores of betweenness for two core actors, i.e. Director and Sub-Director with 32,369 and 29,826 respectively. The previous analysis of the EMobi network, however, revealed that top betweenness was significantly concentrated in one actor. Second, there was a medium score for one actor (i.e. Top Advisor 2 with 18,052) rather than five actors as in the EMobi case. Third, the table reveals low scores in eight actors[159]. Fourth, the table presents null scores (or near) to only six actors[160], significantly different from the EMobi's thirteen remaining actors. To conclude, NanoLab betweenness captures a distribution of the power to influence the decision between several actors, vis-à-vis the concentration found in the two main EMobi actors. This conclusion is in line with the information gathered in the interviews, where all decisions of NanoLab required previous discussions, which were sometimes long and complex, due to the international character of the laboratory (I24, I25 and I26).

The core-periphery structure is another network characteristic similar in spirit to centralization of the network.[161] Core-periphery structures are commonly found in social network data, and have important implications for the functioning of networks. Figure 7.3 (in Annex 2 – Supplementary figures) reveals that a central core and a periphery exist in the network of decision of NanoLab. The core (labelled 1) was comprised of the Ministers of S&T of the two countries, their top advisors and NanoLab's directors. The periphery (labelled 2) contained the remaining actors of the network.[162] It is interesting to note that both Prime Minister 1 and Prime Minister 2 are part of the periphery of the decision process. In fact, according to the interviews held for the NanoLab case, both prime ministers were mostly involved in the formal decision of the NanoLab (I23, I24, I25, I26 and CI2).

Cohesive subgroups could be interesting for further understanding the functioning of a network. In fact, some actors in subgroups interact more with each other than they do with actors who are not in the subgroup. These types of subgroups often share common ideals, goals and/or attributes and form factions within the network. Figure 7.4 (in Annex 2 – Supplementary figures) reveals the existence of

[159] Namely Top Advisor 1, Sub-Director (Temporary), Minister of S&T 2, Minister of S&T 1, scientific staff, Prime Minister 2, the international scientific community, and Prime Minister 1.
[160] Namely, the City Mayor, construction company, equipment company, National Scientific Community 1, National Scientific Community 2, secondary schools, and other academia.
[161] Measures of the core-periphery of a network result essentially by comparing the network with an idealized model (Borgatti, Martin, and Johnson 2013).
[162] Namely, Prime Minister 1, Prime Minister 2, City Mayor, construction company, equipment company, National Scientific Community 1, National Scientific Community 2, the international scientific community, scientific staff, secondary schools, and other academia.

four factions in the network. These factions appeared to be formed sharing common attributes in the decision process. The first faction is composed of those who played a minor role and were less relevant actors/groups in the decision-making process, those being the city mayor, secondary schools and the other scientists excluded from the process. The second faction comprises exclusively scientific actors/groups, which have a common interest in nanotechnology: National Scientific Community 1, National Scientific Community 2 and the Scientific staff of NanoLab. The third faction was made up of those who triggered the decision-making process and launch of the NanoLab project: the prime ministers and the minister of science of the two countries. And the fourth faction is composed of those who had to implement the project of NanoLab.[163]

Similarly to the EMobi case, this social network analysis expanded the comprehension of the organizational context of the decision-making process. In fact, it penetrated, mapped actors and relationships and made explicit the "organizational processes of decision that led to NanoLab. Furthermore, social network analysis provided empirically validated indicators of structure, cohesion and shape of the network and individual actors. The case study allowed for an analysis with objective measures about decision makers' links in a network organized by project, which – as in the EMobi case - evolved organically to implement a policy decision to create a nanotechnology laboratory.

(c) Process of construction of evidence

Some evidence was collected during the decision process of NanoLab. Various elements were discovered about the international context of investments in nanotechnology, particularly in the USA but also at the EU level (Roco et al. 2000; Roco and Bainbridge 2003; Morrison 2005; Hullmann 2006). Furthermore, Spain conducted a significantly detailed study to determine the activities and necessities in the field, and to map and improve technical skills and infrastructures in the period 2005-2010 (Correia, Hernández, and Domingo 2004). In fact, the study extensively included quantified indicators at regional, national and European levels. These indicators included cost of research projects, equipment and skills; number of researchers and technicians and skills; lists of equipment and projects existent in each laboratory; skills required to operate equipment that already existed, ordered and might be ordered in future; etc. Spain also produced other public reports framing the investments in nanotechnology within the S&T system.[164, 165] At the time, investments were planned for six Spanish laboratories (I26). To the central government, NanoLab was part of a larger set of investments requiring negotiation with the Spanish regions, their research communities, and with Portugal. The negotiations required evidence that could be introduced in the assessment of the

[163] Namely, the Top advisor 1, Top advisor 2, Director, Sub-Director, Sub-Director (Temporary), Construction company, Equipment company, and International scientific community.
[164] Comisión Interministerial de Ciencia y Tecnología. 2005a. "Memoria de Actividades I+D+I. 2005." Madrid: Ministerio de Educación y Ciencia.
http://www.idi.mineco.gob.es/stfls/MICINN/Investigacion/FICHEROS/2005-memoria-i-d-i.pdf.
[165] Comisión Interministerial de Ciencia y Tecnología. 2005b. "Plan Nacional de Investigación Científica, Desarrollo E Innovación Technológica (2004-2007) - Programa de Trabalho Para El Ano 2005." Madrid: Ministerio de Educación y Ciencia.

situation and the distribution of the investments. In addition, Portugal did not produce extensive studies on nanotechnology, despite investments in two new associate laboratories (I25). In fact, only the technical committee preparing NanoLab collected elements to map existing research activities in the country (INL Technical Committee 2006). An interviewee argued that the need to justify the distribution of investments was lower than in Spain, and mostly directed at the Portuguese nanotechnology community (I24).

Moreover, no study found in either country demonstrating an explicit need to invest in nanotechnology and nanoscience as opposed to other S&T areas. In fact, the only justifications found were based on the idea that the USA and other developed countries were investing in this research area (I25 and I26).[166] However, this argument is also true for other research areas. Another argument was the need to create the first international research centre in these countries. The argument was based on the scientific, technological and economic benefits to those countries of having an international R&D centres in a emerging field. Therefore, although both countries introduced evidence in the decision process, the collection of evidence was different in the two Iberian countries: In Spain there were detailed preparatory studies with quantified indicators and other evidence, and in Portugal there was an ad hoc mapping of the activities of the existing research groups.

4.3.3.3 Comparative analysis of the social networks

The social networks identified in the case studies can be further compared at the network and the individual level. The following table presents a comparison between the most relevant parameters of cohesion found in EMobi and NanoLab's social networks at network level.[167]

Table 4.16 – Comparison between parameters of network cohesion of EMobi and NanoLab

	Mobi-E	INL	Δ
Centralization	0,538	0,426	0,112
Density	0,253	0,268	-0,015
Connectedness	0,716	0,889	-0,173
Compactness	0,471	0,556	-0,085

Table 4.16 reveals two main features regarding the characteristics of the networks. First, the EMobi network was more centralized than the NanoLab. In fact, the measure of network centralization of EMobi was higher than the NanoLab (0,538 vs. 0,426). A comparison of the EMobi and NanoLab networks indicated higher values of density (0,253 vs. 0,268), connectedness (0,716 vs. 0,889) and compactness (0,471 vs. 0,556). Therefore, at network level, the differences between cohesion measures suggest differences between the social networks. These measures are in line with other

[166] According to Bijker (2014), the history of Dutch engagement with nanotechnologies starts with the introduction of debate in society, in politics and within influential policymakers about nanotechnology by the Rathenau Institute. A report from this technology assessment institute resulted nanotechnologies arriving on the public agenda, though without any explicit positive or negative undertone.

[167] As mentioned previously, the social network analyses were elaborated using UCINET 6 for Windows (Borgatti, Everett, and Freeman 2002).

qualitative findings. Five interviewees pointed to the centralized nature of the EMobi decision process to tightly control the policy (I13, I21, I22 and I25). Furthermore, three interviewees mentioned the intensive nature of the negotiations undergone to reach agreements between the two countries during NanoLab's decision process (I24, I25 and I26). The negotiations required the inclusion of more well-connected actors to allow the development of the decision and to prevent delays (I24 and I25). Therefore, results are aligned with the idea that the two networks have different orientations: one to control the process and the other to negotiate.

At the individual level two measures allow a comparison between actors in the networks: Eigenvector centrality and betweeness. The following table presents these normalized individual measures of EMobi and NanoLab networks.

Table 4.17 – Individual eigenvector centrality and betweeness and their normalized values in the EMobi and NanoLab networks

Case study	Actors	Eigenvector centrality	% of Eigenvector centrality	Betweeness	% of Betweeness
Mobi-E	Prime Minister	0,204	5%	2,444	2%
	Consultancy company 1	0,379	10%	16,290	16%
	Advisor of the Prime Minister	0,454	12%	54,154	52%
	Advisor of the Minister of S&T	0,126	3%	6,150	6%
	Secretary of State of S&T	0,042	1%	0,000	0%
	Minister of S&T	0,159	4%	8,967	9%
	Electric component company 1	0,281	7%	1,144	1%
	Software company 1	0,281	7%	1,144	1%
	Power company	0,281	7%	1,144	1%
	Software company 2	0,281	7%	1,144	1%
	Electric component company 2	0,222	6%	0,000	0%
	Consultant company 2	0,151	4%	0,375	0%
	EV Association	0,000	0%	0,000	0%
	Excluded company 1	0,000	0%	0,000	0%
	Excluded company 2	0,000	0%	0,000	0%
	R&D laboratory on EV	0,160	4%	0,000	0%
	Advisor of the Minister of Economy	0,247	7%	6,527	6%
	Minister of Economy	0,186	5%	1,367	1%
	Secretary of State of Innovation	0,200	5%	3,150	3%
	Advisor of Secretary of State of Innovation	0,133	4%	0,000	0%
INL	Prime Minister 1	0,088	2%	1,000	1%
	Minister of S&T 1	0,163	4%	3,819	3%
	Top advisor 1	0,279	8%	9,795	8%
	Prime Minister 2	0,105	3%	1,786	2%
	Minister of S&T 2	0,219	6%	5,486	5%
	Top advisor 2	0,347	9%	18,052	16%
	City Mayor	0,105	3%	0,000	0%
	Director	0,426	12%	32,369	28%
	Sub-Director	0,433	12%	29,826	26%
	Sub-Director (Temporary)	0,307	8%	9,050	8%
	Construction company	0,188	5%	0,000	0%
	Equipment company	0,188	5%	0,000	0%
	National scientific community 1	0,104	3%	0,000	0%
	National scientific community 2	0,105	3%	0,000	0%
	International scientific community	0,274	7%	1,367	1%
	Scientific staff	0,216	6%	3,450	3%
	Secondary schools	0,139	4%	0,000	0%
	Other academia	0,000	0%	0,000	0%

Table 4.17 shows two main individual features in the networks formed for these decisions. First, they are both centralized in two decision makers. In fact, there is almost the same normalized Eigenvector centrality around the prime decision makers of the two networks: 12% for the Advisor to the Prime Minister and 10% for Consultancy company 1 in the EMobi case study; and 12% each for the Director and Sub-Director in the NanoLab case study. The control of flow of information is significantly concentrated in one decision maker in the EMobi network, but distributed among three actors in the NanoLab case. In fact, there is a higher concentration of betweeness in the Advisor to the Prime Minister (52%) in the EMobi network, and relatively more distributed betweeness in the Director (28%), Sub-Director (26%) and Top Advisor 2 (16%) in the NanoLab case. Therefore, the two networks were centred in two decision makers, and the flows of information were more controlled in the EMobi case and less in the NanoLab network.

In sum, the results of the social network analyses suggest the existence of two different networks formed by a project (a decision) with diverse roles amongst the main actors. First, the EMobi case revealed a close interaction between companies and policymakers in a cohesive small network. The network shape was normally centralized in its middle and significantly centred in the Advisor to the Prime Minister and Consultancy company 1. The network was also closed shortly around its centre, and significantly dependent on the Advisor to the Prime Minister, and actors distant from the core had difficulties accessing information about decisions. Second, the NanoLab case revealed a small cohesive network of policymakers and scientists, centralized in two actors (i.e. Director, Sub-Director) and exhibiting a flow of information distributed among three main actors (i.e. Director and Sub-Director and Top advisor 2). To conclude, it can be argued that the social network analyses expanded the comprehension of the organizational context of these two decisions. They improved the description gathered through interviews and allowed a comparison between the two networks by depicting a spatial visualization of the actors and their relationships and by providing measures to compare the structure, cohesion and shape of the networks to understand the role of indicators.

5. CONCLUSIONS AND DISCUSSION

It was important to conduct research about the role of indicators to expand the understanding of decisions of technology innovation. Literature review detected a gap in knowledge about the role of indicators in these decisions, both in the innovation and technology assessment literature. Existing knowledge was limited to three cases of policies of sustainable development, indicating a minor influential role of indicators in the decisions. Furthermore, the gap in knowledge is significantly important to technology assessment studies. In fact, indicators are critical to produce sound TA studies and to practitioners in this field, where the selection procedure of indicators needs to be as transparent and as thoughtful as possible. Insights into the policy process can also help professionals understand differences between policy, business and research processes. Thus, there was the need to expand the literature to include other innovation areas and actors and to focus on technology innovation with an emphasis on policy-making. Research needed to disentangle use from the influence of indicators, to determine their role, and to study how indicators were used in these decisions. The latter involved the test of four possible explanatory factors: the type, phase of decision and the context and process of construction of evidence.

The use and influence of indicators were identified in decision-making of technology innovation. This quantification effort was necessary to contextualize and differentiate, for the first time, the extent of the use and the influence of indicators in this type of decision. Results showed that the use of indicators in these decisions is significantly high (84%), although slightly differentiated in each group: the vast majority of policymakers use indicators (92%), followed closely by business R&D&I leaders (89%), and then by researchers (71%). However, social relations were more important than indicators to the majority of decision makers (59%). These results were mostly emphasized by policymakers (68%) and business R&D&I leaders (59%), although half of the researchers (50%) considered indicators as important as social influences. The gaps between use and influence of indicators suggest that researchers are more influenced by indicators than business R&D&I leaders and, to a significant extent, more than policymakers. These findings confirmed that the use of indicators is different from their influence, as suggested by Gudmundsson and Sørensen (2012). The gaps between use and influence also suggest differences in the decision processes of these three groups. Furthermore, results revealed that the most important influence in these decisions came from hierarchies, knowledge sources and users of technology. The influence of hierarchies was emphasized by policymakers and business R&D&I leaders; the links to knowledge were most relevant to researchers and, to a lesser extent, policymakers; and the influence of users was significantly relevant to researchers and business R&D&I leaders. Therefore, there is a high use of indicators in these decisions in contrast with their real influence, suggesting that political-behavioural methods were involved in the decisions, and centred on hierarchies, knowledge-based contacts and users.

The results suggest that indicators do not play a very significant role in decisions of technology innovation. There are three main reasons for this: First, indicators had mostly a symbolic role among policymakers (63%) and a limited instrumental role (29%). These results are in line with findings of Gudmundsson and Sørensen (2012), where policy indicators had a very limited direct instrumental role. However, present findings disagree with the widespread non-use of indicators in policy-making, mentioned by MacRae (1985). In fact, only a minority of policymakers (8%) revealed that indicators had no role in their decisions. Second, business R&D&I leaders presented a similar but less emphatic pattern. For them, indicators mostly had a symbolic role in the decisions (53%) and a limited instrumental role (36%). Results suggest that the company's culture was a factor influencing the role of indicators in the decisions. These results are in accordance with the literature reviewed, where company culture influences innovation decisions. Third, the role of indicators for researchers was different. Researchers shown that indicators could play, almost equally, an instrumental (35%) and symbolic (35%) role, as well as no role at all (29%) in their decisions. In sum, results suggest that indicators play mostly symbolic roles in decisions of policymakers and business R&D&I leaders, but their role with researchers can be more differentiated.

Other results about the role of indicators revealed that, despite their problems, they are valued by those working with innovation studies and technology assessment. Indicators have limitations that need consideration: using indicators is an option that implies dealing with what is possible to measure; they limit the perception of reality with restricted reliability; and they can lead to abuse or misinterpretation of data. These limitations are in line with the potential of indicators for deceptiveness that should not be underestimated, as described in subchapter 2.1. Chris Freeman (1995) mentioned that the use of indicators was misleading, for example, when trying to understand the Japanese economic miracle of the 1980s. Furthermore, in line with literature discussed, policymakers and experts agreed that the selection of indicators in innovation policy and technology assessment studies is very sensitive. In fact, the decision to use one indicator instead of another is relevant to policy-making because it can capture a single-sided view of a more complex reality. These sometimes controversial decisions need, therefore, to be transparent and as consensual as possible among actors, stakeholders and in society to reduce room for randomness when making a choice. The best solution is to measure what is possible knowing the limits of indicators, and present what is conceivable given those limits. In addition, the selection process of indicators can entail options that are not neutral, trivial or conscious. In fact, their selection can create an implicit and sometimes controversial space for "politics" in studies that support decision-making, as mentioned in subchapter 2.1. The criteria for selecting indicators may be based on policy relevance, utility, analytical soundness and measurability (OECD 2003). However, results suggest that they can also be based on other (sub)conscious factors that can lead to controversies. In the policy arena, a technology assessment study needs a clear formulation of the initial problem to enable a transparent selection of indicators to describe the problem. Thus, it can be argued that in controversial topics reports should include a detailed description of the decisions regarding inclusion and exclusion of indicators and reflection on possible consequences. In sum, indicators can be helpful to conduct a reasonable interpretation of data and to balance options in technology assessments studies, when contextualised, described in detail and with a reflection about the options made.

Results suggest that the type of decision can be an explanatory factor to understand the way indicators are involved in decisions of technology innovation. In fact, interviewees confirmed that each type of decision requires indicators in different ways. Survey results showed heterogeneous patterns of roles (between instrumental, symbolic and no role) in acquisition of equipment/technology and development of product/technology; and by contrast policy-making was significantly aligned with the symbolic role. Results also showed that the type of indicators varies by type of decision: in decisions of acquisition of equipment/technology indicators used were mostly technical characteristics of technology; in decisions of development of product/technology were both characteristics of technology and costs; and in policy design were costs. Therefore, results suggest that the type of decision can help explain the way indicators are involved in decisions of technology innovation, particularly by differentiating policy-making activities from the other types of decision.

The phase of decision is an explanatory factor to how indicators are used in decisions of technology innovation. Interviews confirmed two important moments - before and after the decision - and these moments included a preliminary evaluation of the potential benefits of the decision in terms of knowledge, competitiveness and/or political assessments. The decision process can include political-behavioural methods before and/or after the final decision. They may include discussion, negotiation, networking, consensus-building and/or other social activities. The decision process can also involve rational-analytical methods before and/or after the final decision, such as collection of indicators, other evidence and/or other analyses. Furthermore, survey results showed that the use of indicators before making a decision was intensive in all types of decision, although less expressive in policy design. After the decision, there was one homogenous pattern in acquisitions of equipment/technology and two heterogeneous patterns among policy design and development of product/technology. Hence, the phase is an explanatory factor to how indicators are introduced in these decisions. In fact, they clearly distinguished two phases detected in all type of decisions, as well as two other phases that can be used to complement the decision process and where indicators can be involved.

The results suggest that the context of the decision and the process of construction of evidence are relevant factors to explain how indicators are involved in the decision process (Hypotheses 5 and 6). The case studies allowed a separation between the context and process of construction of evidence, as well as an identification of the methods used to decide in these policy processes:

– The case studies were useful for revealing the importance of the context to understand how indicators were used in the decision process. EMobi was created in the context of a governmental dynamic and a favourable economic environment conducive to new technological developments and renewable-oriented investments. The decision process was also pushed by a group of companies associated with the government in order to promote electric mobility. The decision to create the NanoLab resulted from an external context of increased investments in nanotechnology research. The idea was internally suggested in a policy briefing and welcomed by both Iberian governments. The organizational process included a creation of a bilateral technical committee with policymakers and scientists to implement the NanoLab project. The strategy was influenced by international scientific advisors and by two experts hired to create an organizational and legal framework. Furthermore, the analyses of the social networks were useful to map and understand the relationships organized to support the decision processes. In fact, the maps of the networks and their measures completed the description of each network by showing an organization engaged by project (a decision), and allowed a comparison between them: the EMobi case revealed a close interaction between a small cohesive network of companies and policymakers, significantly centred on two actors - mainly the Advisor to the Prime Minister and also Consultancy company 1 – information being significantly controlled by the former; the NanoLab case revealed a small cohesive network centralized in two actors (i.e. Director and Sub-Director), but with a distributed flow of information based on three actors. In addition, the two cases had both an internal and external social dynamic influencing the decisions. It included no more than two groups of actors in the innovation system, who managed the social process occurring behind the scenes: in the EMobi case, relationships in a public-private network grew to implement a centralized execution plan; in the NanoLab case, a negotiation network was built to reach swift agreements between two governments and researchers. In sum, the actors formed relationships that grew organically using a combination of different methods to implement a decision. Therefore, the cases revealed two different contexts determined by conducive political and economic environments, and promoted by two or three internal actors in the centre of the networks of the decision.

– The findings from the case studies revealed a different process of construction of evidence. In the EMobi case, the need for the programme was supported by an indicator of penetration rates of EVs in 2020. Other evidence existed and was ignored. Further evidence was solicited to think-tanks, and controversies occurred during the decision process. In the NanoLab case, the evidence was collected to different depths by each country: Portugal mapped existing research activities in the area ad hoc; and Spain collected extensively indicators and other evidence to negotiate the distribution of investments with various regions and the nanotechnology community. Both countries lacked comprehensive evidence to justify the concentration of investment in the field of nanotechnology and nanoscience. Therefore, most evidence was collected to provide a rationale for existing policy decisions, although there was an exception in Spain where indicators pre-existed the decision to create the NanoLab.

The different use of evidence is in line with the literature in two ways: First, Flitcroft et al. (2011) signalled an abundance of possibilities for evidence use: in one extreme, evidence can be strictly identified with scientific outputs; at the other end of the spectrum, evidence can be the subjective selection of the available information introduced in an argument to persuade about the trueness or falsity of a statement. The collection of objective indicators in Spain reveals a use closer to scientific outputs, whereas the use of the indicator of market penetration in 2020 reveals a use closer to persuasion. Second, the findings confirmed the literature stating that the strength and quality of evidence can also be related to the number of controversies that it goes through during its lifetime (Sébastien and Bauler 2013). In fact, in the EMobi case, the indicator of penetration lost much of its strength with the controversies that it went through since its creation. Therefore, these case studies confirmed the literature arguing for a broad use of evidence while also pointing to their decrease in strength due to controversies. To conclude, Hypothesis 6 was confirmed: The process of construction of evidence helps to explain how indicators are used in decisions of technology innovation.

Results about the context and the process of construction of evidence also revealed that the role of indicators and other evidence did not particularly increase when business engineers (with Bachelor's and Master's degrees) and academic scientists (with PhDs) turned into policymakers. In fact, despite their qualifications, these decision makers were not particularly engaged in deeper quests for indicators or other evidence than what they needed to support their decisions. These findings appear to contradict the Musso and Francioni (2012) idea that the educational level is significantly relevant to the decision maker's response. Alternatively, the results appear to be in line with the literature that described contextual situations as an important factor influencing the role of indicators and evidence: Perri 6 (2002) argued that the situations in which policymakers find themselves shape the information that is selected from the complex set available, and which evidence is rejected or at least downplayed. However, the exception to this was the Spanish collection of indicators found in the NanoLab case, where indicators played a more instrumental role in discussing investments. This suggests that the legitimacy of policy arguments in an adversarial policy context (i.e. regional negotiations with the government for investments) depends on the ability of actors to present persuasive analytical evidence, as Sébastien, Bauler, and Lehtonen (2014) recently proposed. In adversarial contexts, policymakers are more likely to use harder analytical indicators, closer to the concept of scientific evidence, than in a more consensual policy decision. Therefore, Hypotheses 5 was confirmed: The context helps to explain how indicators were used in the decisions of technology innovation.

- The two case studies also detected the existence of all three approaches to decision-making, further describing how indicators were used in decisions of technology innovation. As discussed in subchapter 2.1, approaches reveal the main type of thinking dominating attention of individuals during the decisions. In the EMobi case, networking activities were conducted by government and businesses to lead to a positive judgment about the necessity for this policy. This procedure reveals a predominant political-behavioural approach combined with an emotional-intuitive decision. Afterwards, the actors involved in the decision process needed to collect evidence to create a rationale for the decision. This activity reveals a rational-analytical approach in the decision process. Furthermore, in the NanoLab case a judgement was first made about the interest in creating a laboratory, which led to consultations and thereafter to formal negotiation activities between two governments and researchers. These behaviours reveal a predominant political-behavioural approach combined with emotional-intuitive elements. On different occasions, both governments collected evidence to "rationalize" their decisions. These behaviours capture a rational-analytical approach in the decision process. Therefore, the two case studies revealed the presence of all approaches during their decision processes with different emphases, which resemble muddling through approaches. These findings suggest that while innovation policy decisions may include elements of rational thinking, they are also based on other methods supportive of the political process.

In sum, the context and the processes of construction of evidence helped explain the way indicators and other evidence are involved in decisions of technology innovation. First, the analysis of the political, economic and organizational settings revealed the importance of the contextual situation of the decision makers. More importantly, the use of persuasive analytical evidence appears to be related with the adversity of the policy context. Second, the process of construction of evidence revealed that evidence and indicators were brought to decision processes according to their availability and capacity to support the different interests of the actors and the stakeholders. It also revealed that the process of construction of evidence in policy decisions is significantly different from the scientific process. This is particularly relevant to technology assessment professionals who need to engage in both processes, at least. In addition, the process of construction of evidence revealed the combination of three approaches during the decision processes. The rational-analytical approach signalled the use of evidence and indicators in the decision process; while the others suggested that there is space to employ other methods by technology assessment professionals.

To conclude, this work intended to understand the phenomenon of decisions of technology innovation through the lenses of the role of indicators. It can be said that this angle of research contributed to improving the knowledge base of their role in these decisions. In fact, these lenses brought to light the use, influence and role of indicators as well as the main factors affecting their involvement in these decisions. Furthermore, the quantification of their use and influence is important to this new field of research. It is a starting point to contextualize the extent of their real influence in decision-making, particularly in the context of increasing societal calls to involve evidence in the decisions. In addition, this angle showed that indicators are one tool among others to support decisions of technology innovation. In fact, their relatively minor instrumental role suggests that they are mostly a complementary instrument of decision. When used relevantly, indicators can support a decision, but there are other significant influences that need to be taken into account to understand the role they play, such as the social relations of the decision makers and their emotional-intuitive decisions.

Last, it is important to reflect on the limitations of these results. In fact, although some interviews were conducted in other European countries, a significant part of the results were centred in Portugal. This focus relied on the assumption that the behaviour of these innovation actors is not significantly bounded by national or geographic characteristics. However, it can be argued that at least in policy processes (and eventually in business) some differences can be expected in other countries, where cultures and other social and contextual settings might affect the process of decisions. For example, the use of indicators in policy-making was differentiated in the NanoLab case, precisely due to different national contexts. Therefore, it could be interesting to compare these results with other countries/regions. Comparative results could detect variations in the role of indicators in these decisions, for instance, in highly industrialized countries/regions such as Germany/Rhine valley, the USA/Silicon Valley/Boston area and even Japan.

There are also other aspects that could be developed in the future. It could be interesting to study other variables of decision-making not taken into account in this research, such as personality traits, decision styles of the decision maker and decision-making competence of the decision maker. It might also be interesting to compare gender differences with other national/regional contexts where female presence in innovation groups is larger (see female presence in the samples in Table 7.4 in Annex 3 – Supplementary tables). Further, a comparative study with other groups not related to innovation (e.g. managers of low-tech industries, clerks, farmers) could contribute to a better understanding of the role played by uncertainty and complexity in decisions of technology innovation. It could be interesting to compare results on property rights with other innovation systems. Present results suggest that the reduced number of decisions about property rights are most probably related to characteristics of the Portuguese innovation system (which is in line with the findings of Laranja 2009 and Vieira and Fiolhais 2015). A comparative study with other innovation systems might reveal contrasting decision-making characteristics and, even, open up new policy options. Fifth and last, the experience collected during this research points to the need to establish a network to reflect on indicators for TA. In fact, the use of indicators in TA exercises present specific challenges, such as a sensitive selection procedure of indicators, the need to understand political and business processes connected to TA, and the development of multidisciplinary research. This present work was the first to address specifically the use of indicators from a TA perspective. During the course of this research several scientists revealed the need to discuss the difficulties felt when developing their TA topics, because indicators in TA are critical and seldom discussed in other existing research networks, such as EU-Spri Forum[168] or

[168] EU-Spri Forum is the acronym of "European Forum for Studies of Policies for Research and Innovation". The forum aims to strengthen interdisciplinary community of researchers focusing on interdisciplinary dimensions related to policy and governance in the field of knowledge creation and innovation.

ENID[169]. Therefore, it can be argued that there is interest to promote discussion and a larger knowledge-base about indicators for TA among experts working in this field.

[169] ENID is the acronym of "European Network of Indicator Developers". The network aims to promote the cooperation between institutions and individuals engaged in designing, constructing, producing as well as using, and interpreting Science and Technology Indicators.

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ANNEXES

ANNEX 1 – QUESTIONNAIRES

Questionnaire of the researchers group

Inquérito à decisão tecnológica e à utilização de indicadores

Este inquérito demorará cerca de **5 minutos**.

O inquérito é **confidencial** e as respostas serão analisadas de forma **anónima**.

O inquérito pretende **compreender a forma como foram tomadas decisões ligadas à tecnologia** e perceber a sua **relação com a utilização de indicadores**.

1. Que tipo de decisão tecnológica tomou relacionada com a adopção e/ou investimento em tecnologia (escolha a mais importante para a sua actividade)? *

- Aquisição de equipamento / tecnologia
- Desenvolvimento de produto / tecnologia
- Compra de direitos de propriedade intelectual ou autoral (e.g. patentes, marcas, desenho industrial, indicações geográficas, obras literárias e artísticas, programas de computador, domínios na Internet e cultura imaterial)

2. Utilizou algum tipo de indicador na sua decisão? *

Por exemplo, indicadores financeiros, técnicos, organizacionais, etc.

Se responder **Não** salta para a pergunta 6.

- Sim
- Não

3. Quando é que utilizou indicadores na sua decisão? *

	Nunca	Algumas vezes	Muitas vezes
Antes da decisão *	○	○	○
Após a decisão *	○	○	○

4. Indique os 3 indicadores mais relevantes para a sua decisão tecnológica:

- ☐ Utilização da tecnologia por parceiros
- ☐ Utilização da tecnologia pela concorrência
- ☐ Fornecedores (facilidade de relacionamento, suas características, sua tipologia, etc.)
- ☐ Características técnicas da tecnologia, recolhida através da internet, folhetos, feiras, eventos públicos, etc
- ☐ Características técnicas da tecnologia, recolhida através de intermediários (centros de I&D, centros tecnológicos, serviços de consultoria, associações industriais, etc)
- ☐ Disponibilidade de informação (estudos, pareceres, informação sectorial, etc)
- ☐ Qualificação de recursos humanos (internos)
- ☐ Factores ligados à organização do trabalho
- ☐ Custos (aquisição, manutenção, etc.)
- ☐ Indicadores de quota de mercado, de benchmarking, etc

☐ Outros indicadores financeiros (contabilísticos, TIR, VLA, Payback, etc)

☐ Outros. Por favor indique quais:

5. Qual é a sua opinião relativamente à seguinte frase: "Durante o processo de tomada de decisão tecnológica, os indicadores serviram para:"

	Discordo plenamente	Discordo	Concordo	Concordo plenamente
Perspectivar o futuro (aumento da capacidade competitiva, avanços científicos, desenvolvimento de tecnologia, tendências do mercado, desenvolvimento da concorrência, etc.) *	○	○	○	○
Compreender melhor a situação actual em relação ao grau de actualização tecnológica *	○	○	○	○
Confirmar a minha decisão de aquisição / desenvolvimento *	○	○	○	○
Justificar a decisão de aquisição (à entidade de financiamento, a responsáveis políticos, à direcção, aos colegas, aos sócios, etc.) *	○	○	○	○
Caracterizar a aquisição / desenvolvimento *	○	○	○	○
Cumprir formalidades (com entidades financiadoras de projectos nacionais ou europeus, a entidades fiscalizadoras, legislação, certificações, etc.) *	○	○	○	○
Não foram úteis *	○	○	○	○

6. Qual a importância das seguintes pessoas durante o processo de decisão? *

	Irrelevante	Pouco importante	Importante	Muito importante
Direcção / Chefias *	○	○	○	○
Responsáveis financeiros e contabilísticos *	○	○	○	○
Peritos *	○	○	○	○
Colegas *	○	○	○	○
Relações pessoais (conhecidos, amigos, etc) *	○	○	○	○
Utilizadores da tecnologia *	○	○	○	○
Gestores de conta / Consultores comerciais / Vendedores *	○	○	○	○
Meio empresarial / industrial *	○	○	○	○
Investigadores / Académicos *	○	○	○	○
Decisores políticos *	○	○	○	○
Consumidores *	○	○	○	○
Grupo de cidadãos (Associações, grupos de pressão, etc) *	○	○	○	○
Sociedade em geral *	○	○	○	○
Comunicação social *	○	○	○	○

7. Os Indicadores (financeiros, técnicos, organizacionais, etc.) foram mais importantes do que as Pessoas referidas na pergunta anterior? *

○ Sim

○ Não

8. Como percepcionou a sua tomada de decisão? *

	Nunca	Algumas vezes	Muitas vezes

Hierárquica	○	○	○
Solitária	○	○	○
Competitiva	○	○	○
Em colaboração	○	○	○
Com participação de outros intervenientes	○	○	○

9. Se a sua decisão tecnológica se baseou noutros factores não referidos neste questionário, por favor indique quais:

Posso esclarecer consigo algumas das questões abordadas neste inquérito?

○ Sim. Indique por favor o seu email: *

Submit

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Planning or conducting an academic research project?

Questionnaire of the business R&D&I leaders group

Inquérito à decisão tecnológica e à utilização de indicadores

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- ○ Compra de direitos de propriedade intelectual ou autoral (e.g. patentes, marcas, desenho industrial, indicações geográficas, obras literárias e artísticas, programas de computador, domínios na Internet e cultura imaterial)

2. Utilizou algum tipo de indicador na sua decisão? *

Por exemplo, indicadores financeiros, técnicos, organizacionais, etc.

Se responder **Não** salta para a pergunta 6.

- ○ Sim
- ○ Não

3. Quando é que utilizou indicadores na sua decisão? *

	Nunca	Algumas vezes	Muitas vezes
Antes da decisão *	○	○	○
Após a decisão *	○	○	○

4. Indique os 3 indicadores mais relevantes para a sua decisão tecnológica: *

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- ☐ Utilização da tecnologia pela concorrência
- ☐ Fornecedores (facilidade de relacionamento, suas características, sua tipologia, etc.)
- ☐ Características técnicas da tecnologia, recolhida através da internet, folhetos, feiras, eventos públicos, etc
- ☐ Características técnicas da tecnologia, recolhida através de intermediários (centros de I&D, centros tecnológicos, serviços de consultoria, associações industriais, etc)
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☐ Outros indicadores financeiros (contabilísticos, TIR, VLA, Payback, etc)

☐ Outros. Por favor indique quais:

5. Qual é a sua opinião relativamente à seguinte frase: "Durante o processo de tomada de decisão tecnológica, os <u>indicadores serviram para:</u>" *

	Discordo plenamente	Discordo	Concordo	Concordo plenamente
Perspectivar o futuro (tendências do mercado, desenvolvimento da concorrência, aumento da capacidade competitiva, avanços científicos, desenvolvimento de tecnologia, etc.) *	○	○	○	○
Compreender melhor a situação actual em relação ao grau de actualização tecnológica *	○	○	○	○
Confirmar a minha decisão de aquisição / desenvolvimento *	○	○	○	○
Justificar a decisão de aquisição (à entidade de financiamento, a responsáveis políticos, à direcção, aos colegas, aos sócios, etc.) *	○	○	○	○
Caracterizar a aquisição / desenvolvimento *	○	○	○	○
Cumprir formalidades (com entidades financiadoras de projectos nacionais ou europeus, a entidades fiscalizadoras, legislação, certificações, etc.) *	○	○	○	○
Não foram úteis *	○	○	○	○

6. Qual a <u>importância das seguintes pessoas</u> durante o processo de decisão? *

	Irrelevante	Pouco importante	Importante	Muito importante
Direcção / Chefias *	○	○	○	○
Responsáveis financeiros e contabilísticos *	○	○	○	○
Peritos *	○	○	○	○
Colegas *	○	○	○	○
Relações pessoais (conhecidos, amigos, etc) *	○	○	○	○
Utilizadores da tecnologia *	○	○	○	○
Gestores de conta / Consultores comerciais / Vendedores *	○	○	○	○
Meio empresarial / industrial *	○	○	○	○
Investigadores / Académicos *	○	○	○	○
Decisores políticos *	○	○	○	○
Consumidores *	○	○	○	○
Grupo de cidadãos (Associações, grupos de pressão, etc) *	○	○	○	○
Sociedade em geral *	○	○	○	○
Comunicação social *	○	○	○	○

7. Os <u>Indicadores (financeiros, técnicos, organizacionais, etc.) foram mais importantes do que as Pessoas</u> referidas na pergunta anterior? *

○ Sim

○ Não

8. Como percepcionou a sua tomada de decisão? *

	Nunca	Algumas vezes	Muitas vezes

Hierárquica	○	○	○
Solitária	○	○	○
Competitiva	○	○	○
Em colaboração	○	○	○
Com participação de outros intervenientes	○	○	○

9. Se a sua decisão tecnológica se baseou <u>noutros factores</u> não referidos neste questionário, por favor indique quais: *

Posso <u>esclarecer consigo</u> algumas das questões abordadas neste inquérito? *

○ Sim. Indique por favor o seu email: *

Next

0%

Questionnaire of the policymakers group

Inquérito à decisão tecnológica e à utilização de indicadores

Este inquérito demorará cerca de **5 minutos**.

O inquérito é **confidencial** e as respostas serão analisadas de forma **anónima**.

O inquérito pretende **compreender a forma como foram tomadas decisões políticas ligadas à tecnologia** e perceber a sua **relação com indicadores ou outras fontes de informação**.

Idenfique que cargo ocupava quando tomou uma decisão de política relacionada com tecnologia *

- Ministro
- Secretário de Estado
- Assessor político do Ministro
- Assessor político do Secretário de Estado
- Consultor
- Director-Geral
- Técnico Superior da Administração Pública
- Deputado
- Presidente de Câmara Municipal
- Outro cargo. Por favor indique qual:

1. Que tipo de decisão tomou relacionada com a adopção e/ou investimento em tecnologia (escolha a mais importante para a sua actividade actual ou passada)? *

- Concepção de políticas (ideias, programas, medidas, acções, projectos, etc)
- Desenvolvimento de tecnologia
- Aquisição de equipamento / tecnologia
- Outra: Por favor indique qual?

2. Utilizou algum tipo de indicador na sua decisão? *

Por exemplo, indicadores financeiros, técnicos, organizacionais, etc.

Se responder **Não** salta para a pergunta 6.

- Sim
- Não

3. Identifique os indicadores que utilizou ou recomendou para tomar a decisão:

4. Quando é que recomendou ou utilizou indicadores na sua decisão? *

	Nunca	Algumas vezes	Muitas vezes
Antes da decisão *	○	○	○
Após a decisão *	○	○	○

5. Qual é a sua opinião relativamente à seguinte frase: "Durante o processo de tomada de decisão, os indicadores serviram para:"

	Discordo plenamente	Discordo	Concordo	Concordo plenamente
Perspectivar o futuro (aumento da capacidade competitiva, avanços científicos, desenvolvimento de tecnologia, etc.) *	○	○	○	○
Compreender melhor a situação actual *	○	○	○	○
Confirmar a minha decisão Política / Desenvolvimento / Aquisição *	○	○	○	○
Justificar a decisão de Política / Desenvolvimento / Aquisição (à entidade de financiamento, a responsáveis políticos, à direcção, aos colegas, etc.) *	○	○	○	○
Caracterizar a Política / Desenvolvimento / Aquisição *	○	○	○	○
Cumprir formalidades (com entidades financiadoras de projectos nacionais ou europeus, a entidades fiscalizadoras, legislação, etc.) *	○	○	○	○
Não foram úteis *	○	○	○	○

6. Utilizou outro tipo de informação (estudos, pareceres ou informação sectorial) para a sua decisão? *

Se responder **Não** salta para a pergunta **8**

○ Sim

○ Não

7. Se alguns dos indicadores foram relacionados com outro tipo de informação (estudos, pareceres ou informação sectorial) por favor indique quais indicadores?

8. Qual a importância das seguintes pessoas durante o processo de decisão? *

	Irrelevante	Pouco importante	Importante	Muito importante
Responsável político / Direcção / Chefias *	○	○	○	○
Responsáveis financeiros e contabilísticos *	○	○	○	○
Peritos *	○	○	○	○
Colegas *	○	○	○	○
Relações pessoais (conhecidos, amigos, etc) *	○	○	○	○
Utilizadores da tecnologia *	○	○	○	○

Gestores de conta / Consultores comerciais / Vendedores *	O	O	O	O
Meio empresarial / industrial *	O	O	O	O
Investigadores / Académicos *	O	O	O	O
Outros decisores políticos *	O	O	O	O
Consumidores *	O	O	O	O
Grupo de cidadãos (Associações, grupos de pressão, etc) *	O	O	O	O
Sociedade em geral *	O	O	O	O
Comunicação social *	O	O	O	O

9. Os Indicadores (financeiros, técnicos, organizacionais, etc) foram mais importantes do que as Pessoas referidas na pergunta anterior?

Se não utilizou indicadores, por favor ignore a pergunta

O Sim

O Não

10. Como percepcionou a sua tomada de decisão? *

	Nunca	Algumas vezes	Muitas vezes
Hierárquica	O	O	O
Solitária	O	O	O
Competitiva	O	O	O
Em colaboração	O	O	O
Com participação de outros intervenientes	O	O	O

11. Se a sua decisão se baseou noutros factores não referidos neste questionário, por favor indique quais:

Posso esclarecer consigo algumas das questões abordadas neste inquérito?

O Sim. Indique por favor o seu email: *

Submit

0%

ANNEX 2 – SUPPLEMENTARY FIGURES

The EMobi core-periphery

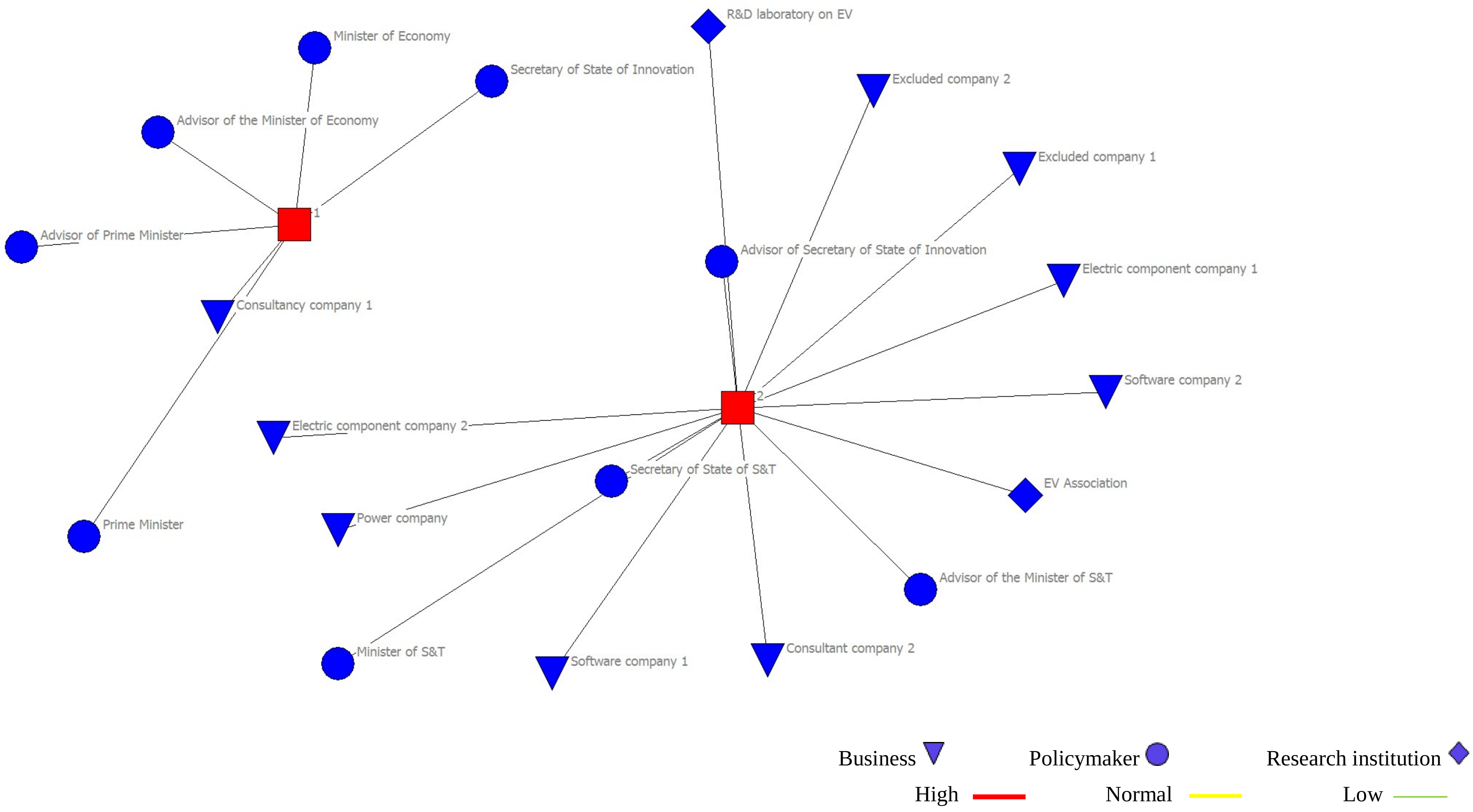

Figure 7.1 – Core and periphery in the network of decision of EMobi

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

The EMobi factions

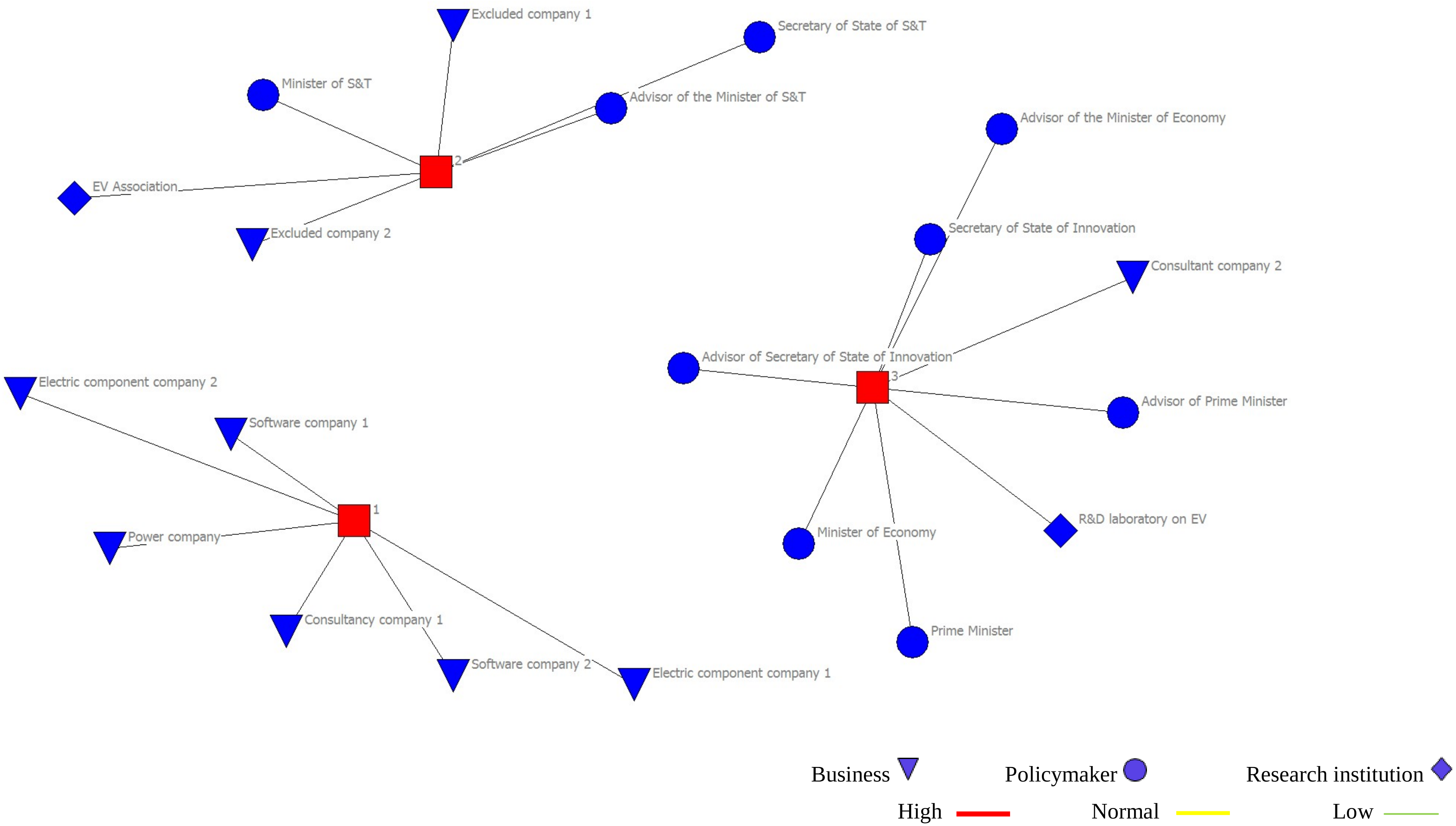

Figure 7.2 – Factions in the network of decision of the EMobi

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

The NanoLab core-periphery

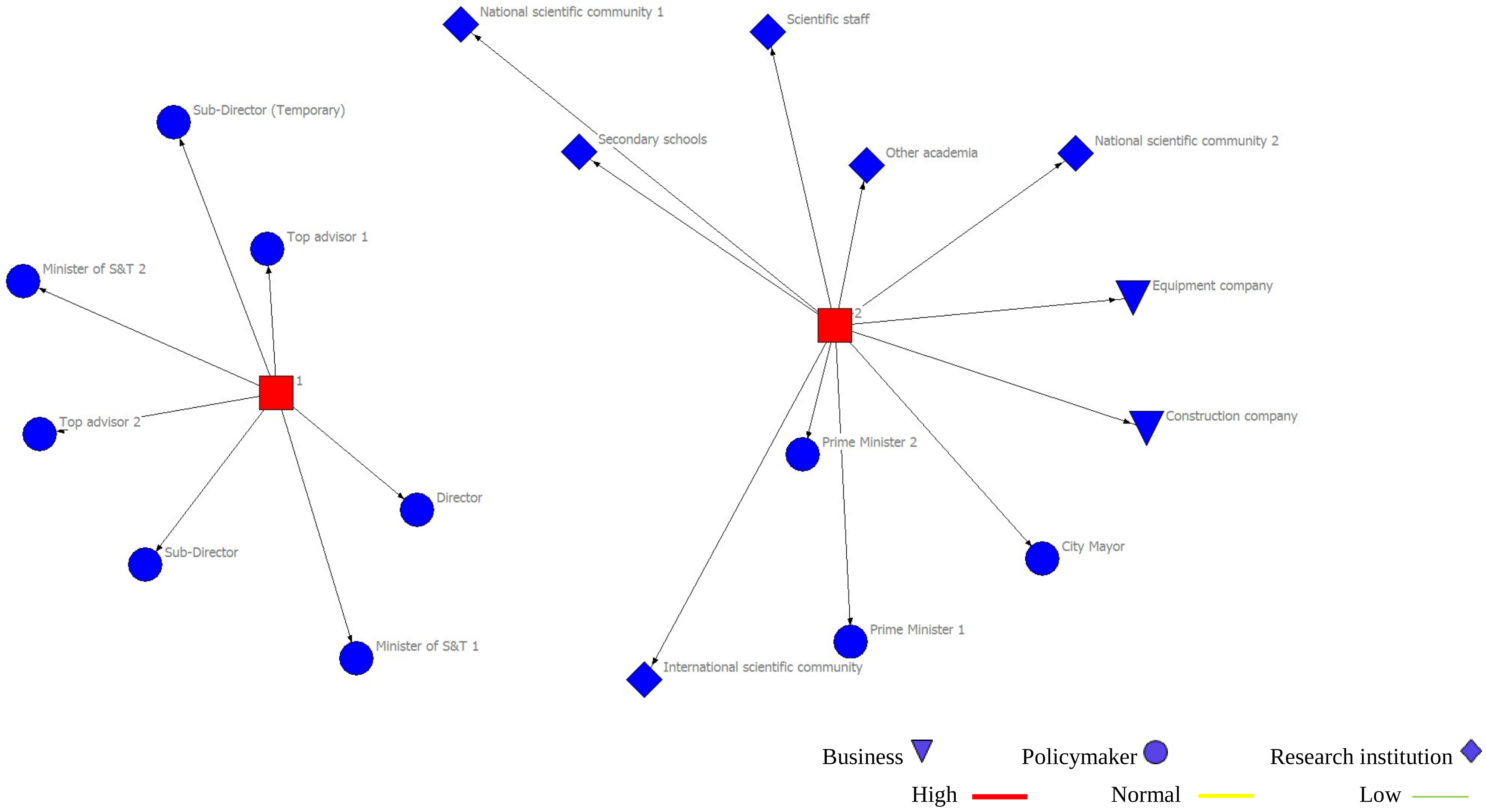

Figure 7.3 – Core and a periphery in the network of decision of NanoLab

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

The NanoLab factions

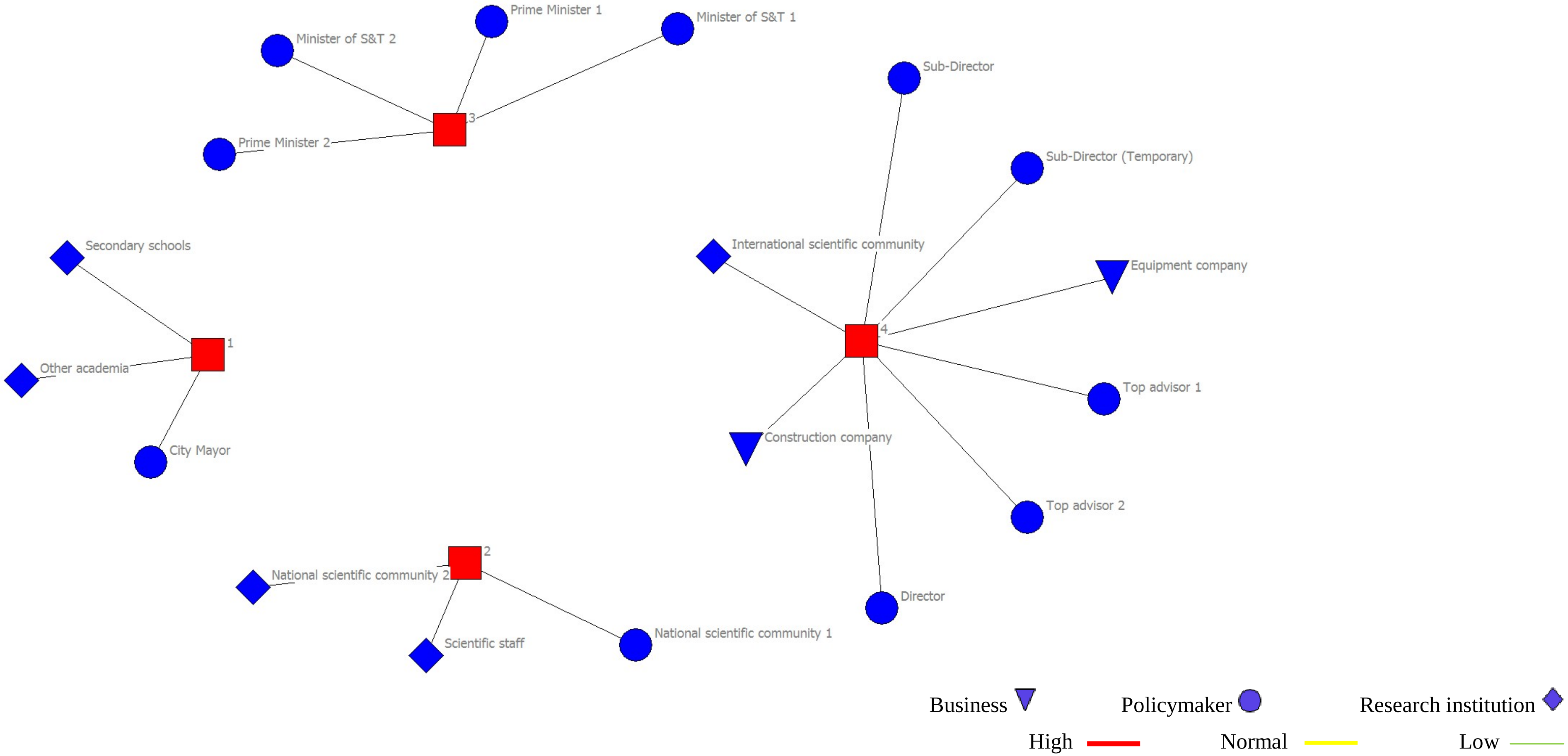

Figure 7.4 – Factions in the network of decision of the NanoLab

Note: Figure elaborated using Ucinet 6 for Windows (Borgatti, Everett, and Freeman 2002).

ANNEX 3 – SUPPLEMENTARY TABLES

Table 7.1 – Number and percentage of answers who totally agree with the purpose of indicators by type of decision

	Acquistion of equipment/technology		Development of products/technology		Acquisition of intellectual property rights		Policy design		Total	
	Answers	%	Answers	%	Answers	%	Answers	%	Answers	%
To deal with the future (increased competitiveness, scientific advances, technology development, etc.)?	13	22%	9	21%	1	33%	11	30%	34	24%
To understand the current situation?	9	16%	7	16%	1	33%	12	32%	29	21%
To confirm your decision of acquisition/development/policy ?	11	19%	8	19%	0	0%	3	8%	22	16%
To justify your decision of acquisition/development/policy (to the financing entity, politicians, management, colleagues, etc.)?	13	22%	10	23%	0	0%	6	16%	29	21%
To characterize the decision of acquisition/development/policy ?	7	12%	3	7%	1	33%	3	8%	14	10%
To comply with formalities (with donors and national projects in Europe, the supervisory bodies, legislation, etc.)?	5	9%	6	14%	0	0%	2	5%	13	9%
Not helpful?	0	0%	0	0%	0	0%	0	0%	0	0%
Total	58	100%	43	100%	3	100%	37	100%	141	100%

Table 7.2 – Sociomatrix of the influence between decision makers of EMobi

	Prime Minister	Consultancy company 1	Advisor of Prime Minister	Advisor of the Minister of S&T	Secretary of State of S&T	Minister of S&T	Electric component company 1	Software company 1	Power company	Software company 2	Electric component company 2	Consultant company 2	EV Association	Excluded company 1	Excluded company 2	R&D laboratory on EV	Advisor of the Minister of Economy	Minister of Economy	Secretary of State of Innovation	Advisor of Secretary of State of Innovation
Prime Minister	0,00	2,00	3,00	0,00	0,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,00	3,00	0,00
Consultancy company 1	2,00	0,00	3,00	0,00	0,00	0,00	3,00	3,00	3,00	3,00	3,00	2,00	0,00	0,00	0,00	3,00	2,00	0,00	0,00	0,00
Advisor of Prime Minister	3,00	3,00	0,00	1,00	0,00	1,00	1,00	2,00	2,00	1,00	0,00	1,00	0,00	0,00	0,00	1,00	3,00	2,00	3,00	3,00
Advisor of the Minister of S&T	0,00	0,00	1,00	0,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00
Secretary of State of S&T	0,00	0,00	0,00	1,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Minister of S&T	2,00	0,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Electric component company 1	0,00	3,00	1,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Software company 1	0,00	3,00	2,00	0,00	0,00	0,00	1,00	0,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Power company	0,00	3,00	2,00	0,00	0,00	0,00	1,00	1,00	0,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Software company 2	0,00	3,00	1,00	0,00	0,00	0,00	1,00	1,00	1,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Electric component company 2	0,00	3,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Consultant company 2	0,00	2,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
EV Association	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Excluded company 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Excluded company 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
R&D laboratory on EV	0,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Advisor of the Minister of Economy	0,00	2,00	3,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	3,00	2,00	3,00
Minister of Economy	3,00	0,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	3,00	0,00	3,00	0,00
Secretary of State of Innovation	3,00	0,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	3,00	0,00	3,00
Advisor of Secretary of State of Innovation	0,00	0,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,00	0,00	3,00	0,00

Table 7.3 – Sociomatrix of the influence between decision makers of NanoLab

	Prime Minister 1	Minister of S&T 1	Top advisor 1	Prime Minister 2	Minister of S&T 2	Top advisor 2	City Mayor	Director	Sub-Director	Sub-Director (Temporary)	Construction company	Equipment company	National scientific community 1	National scientific community 2	International scientific community	Scientific staff	Secondary schools	Other academia
Prime Minister 1	0,00	3,00	1,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Minister of S&T 1	3,00	0,00	3,00	0,00	3,00	0,00	0,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Top advisor 1	1,00	3,00	0,00	0,00	0,00	3,00	0,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
Prime Minister 2	3,00	0,00	0,00	0,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Minister of S&T 2	0,00	3,00	0,00	3,00	0,00	3,00	0,00	0,00	2,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Top advisor 2	0,00	0,00	3,00	1,00	3,00	0,00	1,00	2,00	3,00	1,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
City Mayor	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Director	0,00	2,00	3,00	0,00	0,00	2,00	0,00	0,00	3,00	2,00	2,00	2,00	1,00	0,00	2,00	3,00	1,00	0,00
Sub-Director	0,00	0,00	1,00	0,00	2,00	3,00	0,00	3,00	0,00	2,00	2,00	2,00	0,00	1,00	2,00	3,00	1,00	0,00
Sub-Director (Temporary)	0,00	0,00	0,00	0,00	1,00	1,00	2,00	2,00	2,00	0,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00
Construction company	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	2,00	3,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Equipment company	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	2,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
National scientific community 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
National scientific community 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
International scientific community	0,00	0,00	1,00	0,00	0,00	1,00	0,00	2,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
Scientific staff	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,00	3,00	0,00	0,00	0,00	1,00	1,00	1,00	0,00	0,00	0,00
Secondary schools	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Other academia	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 7.4 – Number and distribution of individuals and females that answer the questionnaires by group

	Females		Total	
	Individuals	%	Individual	%
Researchers	28	36%	78	100%
Business R&D&I	18	32%	57	100%
Policy makers	5	8%	59	100%
All groups	51	26%	194	100%

ANNEX 4 – UCINET FILES

Ucinet Log 1 – Multiple Cohesion measures EMobi

NETWORK COHESION

Input dataset: Dataset (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset

Output dataset: Dataset-coh (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset-coh

Ignore direction of ties: NO (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\NO

Ignore reflexive ties: YES (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\YES

Measures

	Network Cohesion	Measures
1	Avg Degree	4,800
2	H-Index	6,000
3	Centralization	0,538
4	Density	0,253
5	Components	4,000
6	Component Ratio	0,158
7	Connectedness	0,716
8	Fragmentation	0,284
9	Closure	0,542
10	Avg Distance	1,765
11	SD Distance	0,656
12	Diameter	4,000
13	Breadth	0,529
14	Compactness	0,471

For symmetric matrices, Centralization is Freeman's degree centralization.

For non-symmetric matrices, Centralization is indegree centralization.

WARNING: Network is disconnected. Distance-based measures are calculated within components.

Running time: 00:00:01 seconds.

Output generated: 16 Okt 14 21:58:45

Ucinet Log 2 – Multiple Centrality Measures EMobi

MULTIPLE CENTRALITY MEASURES

Input dataset: Dataset (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset)

Output dataset: Dataset-cent (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset-cent)

Treat data as: Auto-detect

Type of scores to output: Raw scores

Undefined dist in closeness: replace with max dist + 1

Network Dataset is directed? NO

Value of Beta was: 0,147231313784649

Centrality Measures

		1	2	3	4	5	6	7	8	9
		Degree	2local	BonPwr	2Step	ARD	Closenes	Eigenvec	Between	2StepBet
1	Prime Minister	5,000	40,000	1.043,409	16,000	10,500	42,000	0,204	2,444	1,500
2	Consultancy company 1	10,000	61,000	1.937,570	15,000	12,833	38,000	0,379	16,290	14,067
3	Advisor of Prime Minister	14,000	75,000	2.324,483	16,000	15,000	33,000	0,454	54,154	42,367
4	Advisor of the Minister of S&T	4,000	27,000	649,066	15,000	9,833	44,000	0,126	6,150	1,750
5	Secretary of State of S&T	2,000	9,000	217,537	6,000	7,250	56,000	0,042	0,000	0,000
6	Minister of S&T	5,000	32,000	814,870	15,000	10,333	43,000	0,159	8,967	3,367
7	Electric component company 1	6,000	47,000	1.433,943	15,000	10,833	42,000	0,281	1,144	0,200
8	Software company 1	6,000	47,000	1.433,943	15,000	10,833	42,000	0,281	1,144	0,200
9	Power company	6,000	47,000	1.433,943	15,000	10,833	42,000	0,281	1,144	0,200
10	Software company 2	6,000	47,000	1.433,943	15,000	10,833	42,000	0,281	1,144	0,200
11	Electric component company 2	5,000	34,000	1.134,756	10,000	9,417	49,000	0,222	0,000	0,000
12	Consultant company 2	3,000	29,000	770,608	15,000	9,333	45,000	0,151	0,375	0,250
13	EV Association	0,000	0,000	0,000	0,000	0,000	95,000	0,000		0,000
14	Excluded company 1	0,000	0,000	0,000	0,000	0,000	95,000	0,000	0,000	0,000
15	Excluded company 2	0,000	0,000	0,000	0,000	0,000	95,000	0,000	0,000	0,000
16	R&D laboratory on EV	3,000	31,000	816,927	15,000	9,333	45,000	0,160	0,000	0,000
17	Advisor of the Minister of Economy	7,000	46,000	1.266,170	16,000	11,500	40,000	0,247	6,527	4,833
18	Minister of Economy	5,000	35,000	951,563	14,000	10,167	44,000	0,186	1,367	1,367
19	Secretary of State of Innovation	6,000	38,000	1.024,424	15,000	10,833	42,000	0,200	3,150	2,700
20	Advisor of Secretary of State of Innovation	3,000	27,000	682,484	14,000	9,167	46,000	0,133	0,000	0,000

Running time: 00:00:01

Output generated: 16 Okt 14 22:01:05

Ucinet Log 3 – Core-Periphery EMobi

SIMPLE CORE/PERIPHERY MODEL

Input dataset: Dataset (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset)

Type of data: Positive

Fitness measure: CORR

Density of core-to-periphery ties:

Number of iterations: 50

Population size: 100

Output partition: CorePartition (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\CorePartition)

Output clusters: CoreClasses (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\CoreClasses)

Starting fitness: 0.789

Final fitness: 0.789

Core/Periphery Class Memberships:

1: Prime Minister Consultancy company 1 Advisor of Prime Minister Advisor of the Minister of Economy Minister of Economy Secretary of State of Innovation

2: Advisor of the Minister of S&T Secretary of State of S&T Minister of S&T Electric component company 1 Software company 1 Power company Software company 2 Electric component company 2 Consultant company 2 EV Association Excluded company 1 Excluded company 2 R&D laboratory on EV Advisor of Secretary of State of Innovation

Blocked Adjacency Matrix

	1 P	2 C	3 A	19 S	17 A	18 M	5 S	6 M	4 A	10 S	11 E	12 C	13 E	14 E	15 E	16 R	7 E	8 S	9 P	20 A
1 Prime Minister		2	3	3		3		2												
2 Consultancy company 1	2		3		2					3	3	2				3	3	3	3	
3 Advisor of Prime Minister	3	3		3	3	2		1	1	1		1				1	1	2	2	3
19 Secretary of State of Innovation	3		3		2	3			1											3
17 Advisor of the Minister of Economy		2	3	2		3		1								1				3
18 Minister of Economy	3		2	3	3							1								
5 Secretary of State of S&T								1	1											
6 Minister of S&T	2		1		1		1		1											
4 Advisor of the Minister of S&T			1	1			1	1												
10 Software company 2		3	1								1						1	1	1	
11 Electric component company 2		3								1							1	1	1	
12 Consultant company 2		2	1			1														
13 EV Association																				
14 Excluded company 1																				
15 Excluded company 2																				
16 R&D laboratory on EV		3	1		1															
7 Electric component company 1		3	1							1	1							1	1	
8 Software company 1		3	2							1	1						1		1	
9 Power company		3	2							1	1						1	1		
20 Advisor of Secretary of State of Innovation			3	3	3															

Density matrix

	1	2
1	2.133	0.536
2	0.536	0.143

Partition saved as dataset CorePartition (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\CorePartition)

Faction-by-actor indicator matrix saved as dataset CoreClasses (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\CoreClasses)

Running time: 00:00:01

Output generated: 16 Okt 14 22:11:45

Ucinet Log 4 – Factions EMobi

FACTIONS

Number of factions: 3

Measure of fit: Hamming

Input dataset: Dataset (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\Dataset)

Initial proportion correct: 0.732

...Badness of fit: 76.000

...Badness of fit: 76.000

...Badness of fit: 76.000

Final proportion correct: 0.800

Group Assignments:

1: Consultancy company 1 Electric component company 1 Software company 1 Power company Software company 2 Electric component company 2

2: Advisor of the Minister of S&T Secretary of State of S&T Minister of S&T EV Association Excluded company 1 Excluded company 2

3: Prime Minister Advisor of Prime Minister Consultant company 2 R&D laboratory on EV Advisor of the Minister of Economy Minister of Economy Secretary of State of Innovation Advisor of Secretary of State of Innovation

Grouped Adjacency Matrix

	11 E	2 C	8 S	9 P	10 S	7 E	6 M	13 E	4 A	5 S	15 E	14 E	1 P	12 C	3 A	16 R	17 A	18 M	19 S	20 A
11 Electric component company 2		3	1	1	1	1														
2 Consultancy company 1	3		3	3	3	3							2	2	3	3	2			
8 Software company 1	1	3		1	1	1									2					
9 Power company	1	3	1		1	1									2					
10 Software company 2	1	3	1	1		1									1					
7 Electric component company 1	1	3	1	1	1										1					
6 Minister of S&T									1	1			2		1		1			
13 EV Association																				
4 Advisor of the Minister of S&T							1			1					1				1	
5 Secretary of State of S&T							1		1											
15 Excluded company 2																				
14 Excluded company 1																				
1 Prime Minister		2					2								3			3	3	
12 Consultant company 2		2													1			1		
3 Advisor of Prime Minister		3	2	2	1	1	1		1				3	1		1	3	2	3	3
16 R&D laboratory on EV		3													1		1			
17 Advisor of the Minister of Economy		2					1								3	1		3	2	3
18 Minister of Economy													3	1	2		3		3	
19 Secretary of State of Innovation									1				3		3		2	3		3
20 Advisor of Secretary of State of Innovation															3		3		3	

Density Table

	1	2	3
1	1.67	0.00	0.38
2	0.00	0.20	0.13
3	0.38	0.13	1.36

Partition saved as dataset FactionsPart (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\FactionsPart)

Faction-by-actor indicator matrix saved as dataset FactionsSets (C:\Users\yd4063\Dropbox\Ucinet\EMobi\6th time\FactionsSets)

Running time: 00:00:01

Output generated: 17 Okt 14 12:18:31

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Ucinet Log 5 – Multiple Cohesion measures NanoLab

NETWORK COHESION

Input dataset: dataset (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset

Output dataset: dataset-coh (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset-coh

Ignore direction of ties: NO (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\NO

Ignore reflexive ties: YES (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\YES

Measures

	Network cohesion	Measures
1	Avg Degree	4,556
2	H-Index	5,000
3	Centralization	0,426
4	Density	0,268
5	Components	2,000
6	Component Ratio	0,059
7	Connectedness	0,889
8	Fragmentation	0,111
9	Closure	0,425
10	Avg Distance	1,853
11	SD Distance	0,659
12	Diameter	3,000
13	Breadth	0,444
14	Compactness	0,556

14 rows, 1 columns, 1 levels.

For symmetric matrices, Centralization is Freeman's degree centralization.

For non-symmetric matrices, Centralization is indegree centralization.

WARNING: Network is disconnected. Distance-based measures are calculated within components.

Running time: 00:00:01 seconds.

Output generated: 16 Okt 14 14:31:11

Ucinet Log 6 – Multiple Centrality measures NanoLab

MULTIPLE CENTRALITY MEASURES

Input dataset: dataset (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset)

Output dataset: dataset-cent (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset-cent)

Treat data as: Auto-detect

Type of scores to output: Raw scores

Undefined dist in closeness: replace with max dist + 1

Network is directed? NO

Value of Beta was: 0,160460242356343

Centrality Measures

		1	2	3	4	5	6	7	8	9
		Degree	2local	BonPwr	2Step	ARD	Closenes	Eigenvec	Between	2StepBet
		--------	--------	--------	--------	--------	--------	--------	--------	--------
1	Prime Minister 1	3,000	13,000	405,277	8,000	8,167	41,000	0,088	1,000	1,000
2	Minister of S&T 1	4,000	25,000	746,921	14,000	9,667	34,000	0,163	3,819	1,583
3	Top advisor 1	6,000	42,000	1277,094	16,000	11,000	30,000	0,279	9,795	4,167
4	Prime Minister 2	3,000	16,000	483,005	10,000	8,500	39,000	0,105	1,786	1,000
5	Minister of S&T 2	5,000	33,000	1000,514	15,000	10,333	32,000	0,219	5,486	2,667
6	Top advisor 2	8,000	50,000	1585,636	16,000	12,000	28,000	0,347	18,052	9,750
7	City Mayor	2,000	15,000	481,980	10,000	8,000	40,000	0,105	0,000	0,000
8	Director	11,000	56,000	1947,055	16,000	13,500	25,000	0,426	32,369	23,000
9	Sub-Director	11,000	57,000	1982,915	16,000	13,500	25,000	0,433	29,826	21,417
10	Sub-Director (Temporary)	7,000	43,000	1405,637	15,000	11,333	30,000	0,307	9,050	5,750
11	Construction company	3,000	29,000	859,153	14,000	9,167	35,000	0,188	0,000	0,000
12	Equipment company	3,000	29,000	859,153	14,000	9,167	35,000	0,188	0,000	0,000
13	National scientific community 1	2,000	16,000	473,211	12,000	8,333	38,000	0,104	0,000	0,000
14	National scientific community 2	2,000	16,000	478,965	12,000	8,333	38,000	0,105	0,000	0,000
15	International scientific community	5,000	41,000	1253,744	16,000	10,500	31,000	0,274	1,367	0,667
16	Scientific staff	5,000	31,000	989,566	13,000	10,000	34,000	0,216	3,450	3,000
17	Secondary schools	2,000	22,000	632,604	13,000	8,500	37,000	0,139	0,000	0,000
18	Other academia	0,000	0,000	0,000	0,000	0,000	68,000	0,000	0,000	0,000

Running time: 00:00:01

Output generated: 16 Okt 14 14:32:19

Ucinet Log 7 – Core-Periphery NanoLab

SIMPLE CORE/PERIPHERY MODEL

Input dataset: dataset (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset)

Type of data: Positive

Fitness measure: CORR

Density of core-to-periphery ties:

Number of iterations: 50

Population size: 100

Output partition: CorePartition (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\CorePartition)

Output clusters: CoreClasses (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\CoreClasses)

Starting fitness: 0.668

Final fitness: 0.671

Core/Periphery Class Memberships:

1: Minister of S&T 1 Top advisor 1 Minister of S&T 2 Top advisor 2 Director Sub-Director Sub-Director (Temporary)

2: Prime Minister 1 Prime Minister 2 City Mayor Construction company Equipment company National scientific community 1 National scientific community 2 International scientific community Scientific staff Secondary schools Other academia

Blocked Adjacency Matrix

		10 S	2 M	3 T	8 D	5 M	6 T	9 S	4 P	7 C	1 P	11 C	12 E	13 N	14 N	15 I	16 S	17 S	18 O
10	Sub-Director (Temporary)				2	1	1	2		2		3	1						
2	Minister of S&T 1			3	2	3					3								
3	Top advisor 1		3		3		3	1			1					1			
8	Director	2	2	3			2	3				2	2	1		2	3	1	
5	Minister of S&T 2	1	3				3	2	3										
6	Top advisor 2	1		3	2	3		3	1	1						1			
9	Sub-Director	2		1	3	2	3					2	2		1	2	3	1	
4	Prime Minister 2					3	1				3								
7	City Mayor	2					1												
1	Prime Minister 1		3	1					3										
11	Construction company	3			2			2											
12	Equipment company	1			2			2											
13	National scientific community 1				1												1		
14	National scientific community 2							1									1		
15	International scientific community			1	2		1	2									1		
16	Scientific staff				3			3						1	1	1			
17	Secondary schools				1			1											
18	Other academia																		

Density matrix

	1	2
1	1.619	0.506
2	0.506	0.109

Partition saved as dataset CorePartition (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\CorePartition)

Faction-by-actor indicator matrix saved as dataset CoreClasses (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\CoreClasses)

Running time: 00:00:01

Output generated: 16 Okt 14 15:19:09

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Ucinet Log 8 – Factions NanoLab

FACTIONS

Number of factions: 4

Measure of fit: Hamming

Input dataset: dataset (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\dataset)

Initial proportion correct: 0.627

...Badness of fit: 64.000

...Badness of fit: 62.000

...Badness of fit: 62.000

Final proportion correct: 0.797

Group Assignments:

1: City Mayor Secondary schools Other academia

2: National scientific community 1 National scientific community 2 Scientific staff

3: Prime Minister 1 Minister of S&T 1 Prime Minister 2 Minister of S&T 2

4: Top advisor 1 Top advisor 2 Director Sub-Director Sub-Director (Temporary) Construction company Equipment company International scientific community

Grouped Adjacency Matrix

	18 OS	17 S	7 C	13 N	14 N	16 S	1 P	2 M	4 P	5 M	3 T	6 T	11 C	10 S	15 I	12 E	8 D	9 S
18 Other academia																		
17 Secondary schools																	1	1
7 City Mayor												1		2				
13 National scientific community 1						1											1	
14 National scientific community 2						1												1
16 Scientific staff				1	1										1		3	3
1 Prime Minister 1								3	3		1							
2 Minister of S&T 1							3			3	3						2	
4 Prime Minister 2							3			3		1						
5 Minister of S&T 2								3	3			3		1				2
3 Top advisor 1							1	3				3			1		3	1
6 Top advisor 2			1						1	3	3			1	1		2	3
11 Construction company														3			2	2
10 Sub-Director (Temporary)			2							1		1	3			1	2	2
15 International scientific communit						1					1	1					2	2
12 Equipment company														1			2	2
8 Director		1		1		3		2			3	2	2	2	2	2		3
9 Sub-Director		1			1	3				2	1	3	2	2	2	2	3	

Density Table

	1	2	3	4
1	0.00	0.00	0.00	0.21
2	0.00	0.67	0.00	0.38
3	0.00	0.00	2.00	0.41
4	0.21	0.38	0.41	1.36

Partition saved as dataset FactionsPart (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\FactionsPart)

Faction-by-actor indicator matrix saved as dataset FactionsSets (C:\Users\yd4063\Dropbox\Ucinet\NanoLab\2nd time\FactionsSets)

Running time: 00:00:01

Output generated: 17 Okt 14 17:24:47